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BUREAU OF PUBLIC ROADS

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SUNDAY TRAFFIC ON ROCKY RIVER BRIDGE—CLEVELAND

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A STUDY OF HIGHWAY TRAFFIC IN THE CLEVELAND REGIONAL AREA[1]

SYNOPSIS OF A REPORT ON A COOPERATIVE INVESTIGATION BY THE UNITED STATES BUREAU OF PUBLIC ROADS AND HIGHWAY AUTHORITIES OF THE CLEVELAND AREA

THE present highways of Cuyahoga County, Ohio, form an incomplete highway transportation system for the free and direct movement of traffic, which is primarily a movement between the suburban centers of traffic and the city of Cleveland, and secondarily between the centers of traffic in the suburban areas of Cuyahoga County.

Outside the cities of Cleveland and Lakewood the survey covered 654 miles of highways in Cuyahoga County, which have been classified as of major, medium, and minor traffic importance. Major roads—those on which traffic now is or by 1937 will be over 1,800 vehicles a day—comprise 291 miles. Medium traffic roads—those which now carry or by 1937 will carry between 700 and 1,800 vehicles a day—comprise 133 miles. The balance of the mileage is of minor-traffic importance. Roads in this class now serve a traffic of 400 vehicles a day or less and it is estimated that their traffic will not exceed 700 vehicles a day by 1937.

TRAFFIC ON CARNEGIE AVENUE

UNSATISFACTORY CONDITION OF ROADS ATTRIBUTED TO SEVERAL CAUSES

Of the major-traffic mileage, 62 per cent, or approximately 179 miles, is now in satisfactory condition to serve traffic demands during the next 10 years, or is under contract for adequate improvement. Of the mileage of medium-traffic routes, 53 per cent, or 70 miles, will be satisfactory for the 10-year period. Only a comparatively small mileage of minor-traffic roads will require reconstruction or widening during the period of the plan.

The remainder of the principal traffic routes (38 per cent of the major-traffic routes and 47 per cent of the medium-traffic routes) of the existing system are in an unsatisfactory condition. There are in addition a considerable number of unimproved gaps in the present system and a lack of arterial routes and connections.

A number of major causes are responsible for the present unsatisfactory condition of the Cuyahoga County system:

1. The lack of a common plan of highway improvement upon which all agencies responsible for road improvements could apply concerted action.

2. The lack of a common plan of highway improvement has been aggravated by the absence of centralized authority and responsibility for road improvements, due largely to the statutory division of responsibility between the county commissioners and the county surveyor, and the situation has been complicated by the constitutional authority of municipal corporations to control the improvement of streets within their limits.

3. The reconstruction of the principal arterial traffic routes, which were originally constructed for light vehicle traffic, has been too long deferred. Under the constantly increasing volume of present-day traffic this policy has resulted in the destruction of the inadequate improvements on these routes.

4. The existing arterial routes between the centers of traffic in the city of Cleveland and the other expanding centers of population and traffic in the county are not sufficient for the proper distribution of traffic.

5. The main-traveled routes of Cuyahoga County and the city of Cleveland converge and unite as they

[1] The final report is now being prepared for publication and the Bureau of Public Roads, upon request, will list the names of those desiring the report and a copy will be forwarded when available.

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approach the central section of the city and create serious problems of traffic congestion.

6. Narrow surfaces on various sections of the main arterial routes in the county and within the city of Cleveland, obstructions to the free movement of traffic, such as grade crossings, street-car lines, street-car loading platforms, parked vehicles, and routes traversing highly developed business and industrial centers result in congested traffic sections and consequently a low-traffic capacity on these main thoroughfares.

7. Unimproved or unsatisfactorily improved sections of the main arterial thoroughfares and an absence of improved connections on important routes between the suburban centers of traffic have resulted in a partially disconnected system of highways and the resulting uneconomic, indirect movement of traffic.

8. Physical obstructions, particularly the river valleys, industrial developments, railroad yards, and park area restrictions, have materially deferred the improvement of present routes or the development of new routes or connections.

INTERESTED HIGHWAY AUTHORITIES AGREE ON COOPERATIVE PLAN

Realizing the increasing importance of the highway problems of Cuyahoga County and appreciating the value of establishing a definite plan of highway improvement to serve the steadily increasing traffic demands of the area, the commissioners of Cuyahoga County requested the cooperation of the Bureau of Public Roads, United States Department of Agriculture, in a study of the highway and traffic problems of the county and in the establishment of a scientific plan of highway improvement.

The Bureau of Public Roads agreed to cooperate in such a study under the following conditions:

1. That the study include the area in which traffic conditions are principally controlled by the city of Cleveland and surrounding suburban area without regard to political boundaries or jurisdictions.

2. That all governmental agencies in the area having jurisdiction over highways and highway traffic cooperate in the establishment of a general highway development plan and agree to carry this plan into execution when established.

3. That the highway studies in the area be continued over a period of years in order to observe the effect which the execution of the plan will have upon the distribution of traffic and upon the efficiency with which traffic is served by a modern highway system.

These conditions were agreeable to the interested highway authorities and a regional committee representing the highway authorities of the area surrounding Cleveland was organized to cooperate in the work. After a preliminary study, the area selected for the highway planning survey designated as the Cleveland regional area, was established within a semicircle of approximately 30-mile radius about the center of the city of Cleveland. This area includes Cuyahoga County and parts of Lake, Lorain, Summit, Geauga, Portage, and Medina Counties, extending in each case to the county seat of these counties. It also includes the principal sources of Cuyahoga County traffic and extends to approximately the limit of local service between Cleveland and its tributary area. Uniform planning for the area as a whole will insure the development of a coordinated system of highways in the several counties and their minor subdivisions.

Resolutions agreeing to cooperate in the establishment and improvement of highways as determined by the survey were adopted by substantially all highway administrative organizations in the area. The cooperative survey was formally approved by the United States Bureau of Public Roads, the Ohio State Department of Highways, the seven boards of county commissioners, and, within Cuyahoga County, by the cities of Cleveland, East Cleveland, Cleveland Heights, Lakewood, and 42 villages and 7 townships.

The cost of the survey was shared equally by the United States Bureau of Public Roads and Cuyahoga County.

Throughout the entire survey excellent cooperation prevailed among all governmental agencies. Each of the counties furnished complete data regarding present highways and structures, and made available all existing records. Suggestions as to required improvements of the system based on local traffic demands were also made by each of the counties and in Cuyahoga County by a large number of the cities and villages. The officials of each of these jurisdictions manifested intense interest in the progress of the work and furnished valuable assistance.

PLAN OF IMPROVEMENT BASED ON COMPREHENSIVE STUDY

The plan of improvement for the highways of the Cleveland regional area has been developed from the following evidence:

1. Present highway traffic.

The daily volume of passenger-car, truck, and bus traffic on each section of the present highway system was determined. A forecast of future traffic was made for each of these sections for 5, 10, and 15 years, and each section was classified as a major, medium, or minor traffic route. This information determined the highway planning requirements necessary for their satisfactory improvement.

2. Distribution of highway traffic.

The origin and destination of traffic operating between the various sections of the area was analyzed to determine the necessity for new routes or connections, and is the basic evidence supporting the plan for new routes and connections.

3. Present condition and estimated life period of existing surfaces and structures.

Each section of the highway system was inspected, analyzed, and classified as satisfactory for 10 years, salvable as sub-base in place, salvable as material, or of no value for reconstruction.

Bridges were classified as satisfactory, requiring replacement, or in need of widening.

Railroad grade crossings were classified either as requiring separation or the installation of modern methods of warning and protection to traffic.

4. Basis of determining proper width of surface for new routes, present highways, and structures.

Traffic capacity analysis of various surface widths ranging from 18 to 40 feet, including traffic time studies and studies of the transverse distribution of traffic on the several classes of surface widths, were completed on the principal routes to determine the economic width of surface required for each section of highway.

5. The present type and width of surface, width of right of way, and maintenance costs for each route.

6. Studies of the density, distribution and trend of population, and industrial growth in the cities and suburban areas.

7. Special studies of arterial, lateral, belt and by-pass routes, relocation of sections of highway, unimproved gaps in the present system, time studies of traffic and train movement at railroad grade crossings, separation of grades at the intersection of heavy traffic routes, and topographical and hydrographic surveys.

8. Conferences with the several county boards, county surveyors, and with the officials of the cities and villages of Cuyahoga County to receive their suggestions and plans for highway improvement.

9. Detailed studies of the cost of construction, using surfaces and structures of modern design, and average prices of construction in the region. This evidence was used as the basis for estimating the cost of the planned improvement.

The facts which have resulted in the final plan of improvement were assembled and analyzed at Washington, independent of local influence.

The resulting plan of new routes and connections, of new construction on existing routes, and reconstruction and widening of present surfaces, and of bridge construction and grade separations, has been approved by the United States Bureau of Public Roads, the Ohio State Department of Highways, the county boards of Cuyahoga, Lake, Lorain, Summit, Medina, Geauga, and Portage Counties, the city of Cleveland, and other cooperating agencies.

LARGE VOLUME OF TRAFFIC NOW CARRIED BY PRINCIPAL ROUTES

Local traffic, particularly between Cleveland and its suburbs and between the larger centers of population within the regional area, constitutes the bulk of the highway traffic. On 15 main routes in Cuyahoga County it was found that only 2.4 per cent of the passenger-car traffic had both origin and destination outside of the county and that only 1.5 per cent was crossing the regional area between outside points. On the same roads it was found that 3.7 per cent of the passenger-car traffic was composed of cars owned in counties of Ohio outside the regional area and 4.7 per cent of cars owned in States other than Ohio.

United States Route 20 carries the largest volume of foreign traffic, i. e., traffic of cars registered in States other than Ohio. On Labor Day, the day of maximum foreign traffic during the survey, 12 per cent of the traffic on this route at the Rocky River Bridge crossing and on Euclid Avenue at Green Road was of this class.

Sunday is the day of maximum traffic except in the business section of the city. Sunday traffic is proportionately greater on roads of low traffic density. On roads carrying less than 1,000 vehicles on an average week day, the Sunday traffic is increased to approximately 240 per cent of the week-day volume. On routes carrying between 5,000 and 10,000 vehicles, the Sunday traffic increased only 30 per cent over the week-day traffic. A considerable part of the Sunday traffic seeks the less heavily traveled routes for pleasure trips.

The improvement of major and medium traffic routes, the widening of major routes, and the creation of new routes will solve the problem of the distribution of Sunday traffic and eliminate the congestion which prevails during peak periods on Sunday at the traffic "bottle necks."

In the regional area the hour of maximum traffic occurs on Sunday between 4 p. m. and 5 p. m.; during this hour the traffic amounts to approximately 10 per cent of the total Sunday traffic. On week days the hour of maximum traffic is between 5 p. m. and 6 p. m. During each of the four hours between 4 p. m and 8 p. m. traffic is greater than during the maximum morning hour, which occurs between 7 a. m. and 8 a. m., when the density of traffic is 152 per cent of that of the average hour.

Traffic was counted at 973 points on the roads of the regional area and 722 of these points were located in Cuyahoga County. The greatest traffic density[2] recorded was on the Superior high level bridge in Cleveland where the average daily 24-hour traffic was 56,000 vehicles.

TRAFFIC ON SUPERIOR HIGH-LEVEL BRIDGE

Within the city, traffic on the main arterial routes was: 38,000 on Carnegie Avenue at East Fifty-fifth Street; 33,000 on Superior Avenue at East Fifty-fifth Street; 32,000 on Bulkley Boulevard at its junction with West Twenty-fifth Street; 28,000 on Euclid Avenue at East Fifty-fifth Street and 32,000 east of its junction with Superior Avenue; 25,000 on West Twenty-fifth Street at the junction with Broadview Road; 22,000 on Woodland Avenue at East Fifth-fifth Street; 21,000 on Broadway at East Fifty-fifth Street; 16,000 on Lorain Avenue at Denison Avenue; and 14,000 on Detroit Avenue at West Twenty-fifth Street.

Table 1 shows the density of traffic on the principal radial routes at 7, 10, and 13 miles from the Cleveland public square. Euclid Avenue and Lake Shore Boulevard are the heaviest-traveled routes at and beyond 7 miles. The necessity of a relief route in this territory is apparent.

[2] Density of traffic is defined as the number of motor vehicles passing any given point on a highway in a unit of time.

TABLE 1.—*Daily 24-hour traffic density on the principal radial routes at points 7, 10, and 13 miles from Cleveland public square*

Road[1]	Traffic at 7 miles	Traffic at 10 miles		Traffic at 13 miles	
		Density	Percentage of traffic at 7 miles	Density	Percentage of traffic at 7 miles
Euclid Avenue	22,826	10,176	45	8,614	38
Lake Shore Boulevard	17,700	12,522	71	8,213	46
Mayfield Road	11,403	5,177	45	2,447	22
Detroit Road	10,616	7,091	67	2,590	24
West Lake Road	9,301	5,444	58	3,371	36
Cedar Road	6,324	3,832	61	2,802	44
Wooster Pike	5,802	4,114	71	3,535	61
Lorain Avenue	5,470	1,955	36	931	17
Kinsman Road	5,166	----------	----------	1,469	28
St. Clair Avenue	4,453	1,909	43	447	10
South Woodland Road	4,237	1,511	36	1,065	25
Miles Avenue	4,073	2,039	50	1,775	44
State Road	3,975	1,128	28	1,030	26
North Woodland Road	3,886	778	20	505	13
Brecksville Road	2,880	1,952	68	1,879	65
Broadview Road	2,590	2,122	82	1,642	63
Ridge Road	880	434	49	483	55

[1] Center Ridge Road and Broadway are not included because of the poor condition of the highway in the 7-mile zone.

Those roads which are not a part of through routes or which serve sections of low population density show a much more rapid decrease in traffic volume with increasing distance from Cleveland. St. Clair Avenue, Lorain Avenue, and North Woodland Road are in this class.

In several cases the traffic as recorded on these routes was influenced by the condition of the routes or of parallel routes at the time of the survey.

The present zone of heavy traffic in Cuyahoga County corresponds generally with the area of Cleveland and the important suburban development—approximately within the limits of Clague Road on the west, Pleasant Valley Road on the south, and Richmond Road on the east. Outside of this area large volumes of traffic are found only on the principal arterial routes connecting Cleveland with adjacent centers of population such as Akron, Lorain, Elyria, and Painesville.

With continued suburban development this zone of heavy traffic will expand slowly, but the change during the next 10 years is expected to be primarily an extension along the present main arterial routes rather than a general expansion of the area.

CONVERGING ROUTES RESULT IN SERIOUS CONGESTION

Principal traffic routes radiate from any center of population like the spokes of a wheel, the routes converging on the business center as a hub. It is a natural development that routes should come together as a city is approached. In the Cleveland area, traffic congestion resulting from this natural convergence, has been intensified by the topography of the area and by the absence of a sufficient number of connected radial routes in and adjacent to the city

The most serious points of congestion are the following:

1. Euclid Avenue (United States Route 20) east of its junction with Superior Avenue, which forms the main traffic artery for the entire northeastern section of the area. Average daily traffic at this point is 32,300 vehicles.
2. Cedar Glen Road at the Cleveland city line where Murray Hill Road, Euclid Heights Boulevard, the Mayfield-Kenilworth connection, Cedar Road, and Fairmount Boulevard converge, producing a daily traffic of over 36,000 vehicles.
3. Woodland Avenue which west of East Fifty-fifth Street carries the combined traffic of Woodland Avenue, Shaker Boulevard, Buckeye Road, and Kinsman Road, a daily traffic of 22,000 vehicles.
4. Broadway, which, southeast of its junction with East Fifty-fifth Street, carries the combined traffic of Broadway, Turney Road, Warner Road, Miles Avenue, East Seventy-first Street, and Union Avenue, a daily traffic of approximately 21,000 vehicles.
5. West Twenty-fifth Street at the Brooklyn-Brighton Bridge, which carries the combined traffic of Wooster Pike, Brook Park Road, York Road, Ridge Road, State Road, Broadview Road, and Schaaf Road, a combined daily volume of 25,000 vehicles.
6. Rocky River Bridge, where West Lake Road, Detroit Road, and Wooster Road converge, producing an average daily traffic of 20,000 vehicles and a Sunday traffic of 28,000 vehicles.
7. The high-level bridge, the west end of which is at the convergence of Bulkley Boulevard, Detroit Avenue, and West Twenty-fifth Street, into which has poured the traffic of Franklin Avenue, Fulton Avenue, and a considerable part of the traffic from Lorain Avenue, forming a daily total of 56,000 vehicles.

Convergence of the principal traffic routes presents a volume of traffic which is far in excess of the normal traffic capacity of present routes coming into the city. An adequate highway system must provide relief for each of these congested sections and provide solutions which will prevent future congestion. The most satisfactory method of providing such relief is to distribute and diffuse traffic over a series of parallel routes and prevent the concentration of such great volumes of traffic on a comparatively small number of routes.

The alternative solution involves the widening of existing main arteries which are frequently through areas so highly developed as to make the cost of widening prohibitive.

Full use should be made of available right of way on these routes; but wherever practicable the solution sought is to develop parallel distributing routes either by the establishment of new highways or the development of proper connections between existing routes and completion of gaps which now exist. This method of solution is the basis of the plan formulated for new routes and connections. It is considered best both from the standpoint of effective distribution of traffic and cost of the improvement. In the case of each of the major congested sections it is entirely feasible to develop parallel routes to the center of the city, equally direct and equally desirable for traffic use. For those sections requiring more than one relief route it is practicable to develop two distributing routes, one on each side of the congested sections, providing new direct routes, and relieving congestion on existing routes.

VARIOUS OBSTRUCTIONS IMPEDE FLOW OF TRAFFIC ON MAIN ARTERIES

In addition to the congestion caused by convergence of main arteries of travel, traffic is further impeded by various obstruction to free movement such as inadequate street width, street-car lines, parked vehicles, cross traffic from intersecting routes, and local business, commercial or amusement developments. The traffic capacity of a highway is fundamentally dependent on the number of free traffic lanes, and the capacity of an entire route may be greatly reduced by a relatively short

section on which the number of traffic lanes is less than on the remainder of the route.

Wherever a main arterial route passes through a local business, theatrical or other amusement area the parking problem becomes critical, and street capacity is reduced by slowly moving vehicles such as cars seeking a parking place and delivery trucks. These conditions are clearly illustrated on Euclid Avenue, with a minimum roadway of 50 feet, equivalent to five traffic lanes, which is frequently reduced to two active lanes due to street-car loading platforms and vehicle parking. In the vicinity of the East One hundred and fifth Street business and theatrical district the traffic capacity is materially reduced by slowly moving local traffic. Where Euclid Avenue crosses this area traffic speed during the peak hours was only 9 miles per hour as indicated by time studies.

Main traffic arteries crossing important rail lines at grade results in a marked reduction of traffic capacity of the route as well as constituting accident hazards.

At the Lorain Avenue crossing of the main line of the New York Central Railroad the crossing is blocked 20 per cent of the time between 7 a. m. and 7 p. m., and over 30 per cent of the vehicles using this heavily traveled route are stopped at the crossing by the closing of the highway for train movement.

LARGE INCREASE IN TRAFFIC EXPECTED IN THE NEXT 10 YEARS

Unless relief is provided in the near future, conditions in the congested sections of the area will become progressively more critical, since the volume of traffic is rapidly increasing. Studies of traffic growth over a period of years in several States have shown that the traffic on the highways of an area increases in the same ratio as the increase in motor-vehicle registration. An analysis of population growth and of the relation of motor-vehicle ownership to population—i. e., persons per registered car—indicates that an increase in traffic of 73 per cent may be expected on the highways of Cuyahoga County during the next 10 years.

In the surrounding counties the rate of increase for the 10-year period is expected to range from 85 per cent in Summit County and 58 per cent in Lorain County to 17 per cent in Geauga County and 13 per cent in Medina County.

DISTRIBUTION OF TRAFFIC IN THE AREA STUDIED

To determine whether present roads in the regional area provide direct highway service between important residential, business, and suburban areas and to determine the approximate location of new routes for the relief of traffic congestion, it was necessary to know the principal sources of traffic in the area. The planning survey was directed not only toward the adequate improvement of present routes but also toward the establishment of new routes and the coordination of all routes so that traffic would travel over the most direct route possible and with the least possible congestion and loss of time.

To accomplish this purpose passenger-car traffic was stopped at key locations on the principal roads and a record was made of the places of origin and destination of each trip. Additional information was also noted concerning the route followed; a description of the route traveled, if indirect, and the reason for choosing it; whether the trip was made regularly a certain number of times per day or week; and, in the case of vehicles traveling through the city of Cleveland, whether the driver would, if proper highway facilities were provided, prefer to avoid driving through the down-town business section of the city.

The places of origin and destination were recorded by street address within the city of Cleveland and these were subsequently grouped into 24 sections within the city. In Cuyahoga County outside of the city the records were classified by city, village, or township. In all, 82 distinct areas were so considered in Cuyahoga County. Larger sections were used outside of Cuyahoga County.

In the analysis of these trips according to place of origin and destination it was found that traffic was predominantly local in character, that the principal movement of traffic in Cuyahoga County was between Cleveland and its suburbs, and that the movement between the suburbs themselves was small in volume when compared with the movement of traffic into and out of Cleveland.

In Cleveland the principal section of source and destination of traffic is the down-town business district,

FLOW OF TRAFFIC IS SERIOUSLY OBSTRUCTED BY STOPS AT GRADE CROSSINGS

the area bounded by East Twelfth Street, Euclid Avenue, and the Cuyahoga River. One-fifth of the total traffic between the entire city of Cleveland and its suburbs is to or from the down-town business section. Over 21,000 cars a day travel between this section and points beyond the city area on the principal traffic routes and this total would be still greater if traffic over the less-important roads was included.

The following figures indicate the volume of traffic between the more distant outlying points and the business district of Cleveland: Between this section and Lake County and points east there is an average daily traffic of 2,100 cars using Lake Shore Boulevard or Euclid Avenue. Between points west of the Rocky River and operating over the Rocky River Bridge and to the downtown district there are over 1,200 cars per day. Between the business district and points south of Brook Park Road, there is a daily traffic of approximately 3,000 cars operating over West Twenty-fifth Street. It is apparent that this traffic from points outside the city area to the business section as well as traffic to other central sections of the city could advantageously be rerouted over new routes to avoid congested sections of roads outside the city and streets within the city proper.

WIDTH OF PLANNED IMPROVEMENTS BASED ON CAREFUL STUDY

The highway improvement required has been determined by a comparison of the highway demands resulting from present and expected future traffic, with the layout and physical condition of the existing highway system. Facts concerning the present highway system were obtained by a detailed survey of each route to determine the type, condition and width of pavement and also the width and condition of all bridges and structures.

On the basis of traffic-capacity studies it was determined that the traffic capacity of a two-lane roadway under open road conditions at a traffic speed of 25 miles per hour is approximately 10,000 vehicles per day. Under suburban conditions with a limited amount of parking adjacent to the roadway, and a larger volume of cross traffic and local traffic the capacity of a two-lane roadway is reduced to approximately 8,000 vehicles per day.

Routes now carrying or expected to carry 8,000 or more vehicles per day within the zone of Clague Road, Pleasant Valley Road, and Richmond Road should therefore be planned as 40-foot roadways to serve four lanes of traffic. Routes outside of this zone carrying or expected to carry in excess of 10,000 vehicles per day should be similarly improved. For those routes within the zone of Clague Road, Pleasant Valley Road, and Richmond Road, not expected to carry more than 8,000 vehicles daily during a 15-year period,[3] a two-lane 20-foot surface is adequate, while a similar surface is adequate for routes outside of this zone and not expected to carry more than 10,000 daily vehicles during the next 15 years.

A CHANGE IN WIDTH OF SURFACE AT VILLAGE LIMITS WHERE THERE IS A CHANGE IN JURISDICTION

PLAN OF HIGHWAY IMPROVEMENT OUTLINED

The plan of highway improvement, when its construction is completed, will provide satisfactory highway facilities for present and expected future traffic. Principles of economy require that where practicable, traffic demands should be met by the improvement of the present highway system. The first requirement of the plan is to utilize the present established routes to the fullest possible extent. This involves a program of widening and reconstruction of present surfaces and structures and new construction on established routes. The widening program consists of widening present pavements to the width required by the volume of present and expected future traffic or to the width possible on existing or obtainable right of way.

The condition of the surface on a considerable mileage of present routes necessitates reconstruction as well as widening. On a few routes where present width is adequate reconstruction without widening is essential. The new construction program on established highways involves the improvement of routes or sections of routes that have not been improved, or of sections on which present improvements are in such poor condition as to be worthless except possibly as salvaged material.

In all cases the proposed width is determined by traffic demands; the type of improvement by the traffic volume and composition and the physical condition of the pavement. On the highways limited to 20-foot pavement width, space for parking vehicles, where required, must be provided outside of the 20-foot surface. The construction program is shown in Figure 1.

In each of the counties of the regional area, highway reconstruction and widening has been in progress for some time. In Cuyahoga County a large number of vitally necessary reconstruction and widening improvements on the main arterial routes have been completed or initiated during the past year. The following are the more important of these projects:

Wooster Road: Rocky River Bridge to Lorain Avenue.
Center Ridge Road: Wooster Road to the east limits of Dover Village.
Lorain Avenue: Rocky River to the Lorain County line.
Wooster Pike: York Road to the Medina County line.
State Road: Near Ridgewood Drive to the Medina County line.
Brecksville Road: Rockside Road to the Summit County line.
South Miles Road: Warrensville Center to the Geauga County line.
North Miles Road: Green Road to Chagrin Falls.
South Woodland Road: Warrensville Center Road to the S. O. M. Center Road.
North Woodland Road: Belvoir Boulevard to the S. O. M. Center Road.
Mayfield Road: Warrensville Center Road to the Geauga County line.
Lee Road: Miles Avenue to the south limits of Shaker Heights village and Monmouth Road to Superior Road.
Warrensville Center Road: Mayfield Road to the south limits of Shaker Heights village.

These improvements, initiated prior to or during the period of the cooperative survey, are generally in agreement with the findings of the survey, and reduce considerably the reconstruction and widening program of Cuyahoga County which is necessary during the 10-year period of the plan.

NEW ENTRANCES TO THE CITY OF CLEVELAND PLANNED

A complete highway system for adequate traffic service requires the establishment of a number of new routes and connections between present routes. Certain sections of the area are inadequately served by present highways owing to lack of direct routes. In other sections the traffic demand exceeds the capacity of existing routes even after proposed improvements of these routes are completed. In these areas new routes must be developed. The location of these new routes and connections is shown in Figure 1. In each case the location is determined (1) by traffic density and distribution and (2) by the engineering possibility and practicability of development on the proposed locations.

[3] Highway widths are established on the basis of expected traffic for a 15-year period on the theory that roads requiring construction or reconstruction should be made adequate for a considerable part of their life period. The established plan covers required improvements for a 10-year period only, but the roadway width on routes requiring improvement during the 10-year period is made adequate to serve traffic for a 15-year period.

FIG. 1.—PLAN OF HIGHWAY IMPROVEMENT IN THE CLEVELAND REGIONAL AREA. BRIDGES AND STRUCTURES FOR GRADE CROSSING ELIMINATIONS ARE NOT SHOWN

1. One of the most important of these proposed new routes is an east-west arterial highway near the lake shore. This route from the east begins at a junction of United States Route 20 just east of Painesville, and runs parallel to and north of the New York Central Railroad, connecting with the present terminus of St. Clair Avenue. St. Clair Avenue is then utilized to Bliss Road. From this point a partial new right of way is necessary, using parts of Waterloo Road and the proposed Grant Boulevard through Bratenahl and thence through Gordon Park to an overpass with connections to East Seventy-second Street. Thence, from East Seventy-second Street, a lake-front route is planned to the central section of the city with connections to East Fifty-fifth Street, East Fortieth Street, and East Ninth Street.

From East Ninth Street the route extends west, by-passing the business section of the city with connections to West Third and Sixth Streets and over a new high-level bridge in the vicinity of the present Main Street Bridge to a connection with Bulkley Boulevard. From this point present highways are utilized to a location on Lake Avenue where a lake-front crossing of Rocky River to a connection with West Lake Road in Rocky River Village is planned. This route provides a fast arterial route to the center of the city from the north-eastern section and will serve as a relief route for Euclid Avenue, Superior Avenue, and the present Lake Shore Boulevard-St. Clair route.

On the basis of present traffic a minimum of 6,700 daily vehicles would have used the eastern section of this route had it been built in 1927 and a minimum of 12,000 daily vehicles would have used the lake-front section from East Seventy-second to East Ninth Street. The proposed Cuyahoga and Rocky River bridges and connections will greatly facilitate movement between the west side and the public square and east-side sections. The present Main Street low-level route crossing the Cuyahoga River valley north of the high-level bridge carries 7,000 vehicles a day, and clearly shows the influence of congestion on the approaches to the Superior high-level bridge. It is estimated that a minimum of 5,000 daily vehicles will use the Rocky River crossing and 18,000 daily vehicles will use the Cuyahoga River crossing from Bulkley Boulevard to East Ninth Street. This route would permit a direct movement between centers of traffic on the east side and the west side without passing through the congested public-square section.

Willow. The western Valley Road branch will carry, on the basis of 1927 traffic, a minimum of 9,000 vehicles per day, the eastern branch a minimum of 5,000 and the elevated section north of the fork a minimum of 14,000 vehicles per day from the intersection to its Broadway connection at Jefferson Street.

3. A third major project involves the development of a depressed highway without cross-street connections from the present terminus of Shaker Boulevard at Woodhill Road to Broadway in the vicinity of Pittsburgh Avenue and East Thirty-fourth Street. This project will afford a relief route for Euclid Avenue and Carnegie Avenue on the north and for Woodland Avenue and Kinsman Road on the south. With the extension of Chester Avenue from East Fifty-fifth Street to a connection with Euclid Avenue at approximately East One hundred and seventh Street which is now under way by the city of Cleveland, a parallel route will be provided on either side of the present badly congested routes, Euclid Avenue and Carnegie Avenue.

Vehicles Parked in the Down-Town Section. A Large Portion of These Cars Travel Daily to This Section

2. The most important new route south of the city requires the development of an arterial route through the lower Cuyahoga River Valley with branches to both the east and west sides of the upper valley, thus providing relief routes for Broadway on the east and West Twenty-fifth Street on the west, two of the most seriously congested approaches to the business center of Cleveland. This project involves an elevated highway from Broadway at Jefferson Street connecting with the proposed similar structure at this location, to a point south of the present junction of Independence Road and Campbell Road. At this point the proposed route forks, the western branch going across the valley and connecting with Broadview Road, State Road, Pearl Road, Brook Park Road, and tapping all the important arterial routes from the south and west. The eastern Independence Road branch connects with Washington Boulevard, and East Forty-ninth Street, to a circular intersection with East Seventy-first Street, Warner Road, Granger Road, Brecksville Road, Canal Road, and the proposed Brook Park east-west belt line at

4. A fourth major project is the completion of a belt line primarily for local traffic distribution around the city of Cleveland. The southern belt route utilizes Brook Park Road and is projected eastward from approximately Schaaf Road to a connection with East Seventy-first Street, Brecksville Road, Warner Road, Canal Road, and the eastern fork of the proposed Cuyahoga Valley route at Willow, thence east to a connection with the southern terminus of East Boulevard, Lee Road, and Warrensville Center Road and via Miles Avenue with other north-south roads east of the city. The western Brook Park belt route is projected across Rocky River to a connection with Spencer Road and thence directly west, intersecting the important arterial routes of this section, in a direct line to the southern part of the city of Lorain. On the west side of Cleveland, Spencer Road is projected north from its connection with the Brook Park belt route to West Lake Road and its connection with the Lake Front Boulevard route to the east. These routes, Spencer Road and the western extension of Brook Park

Road, Brook Park Road and its eastern connections, and the series of parallel routes, East Boulevard in the city, Lee Road, Warrensville Center Road, Richmond Road, and eastern routes form a complete belt line route around the city with connections to all important highways.

This belt system forms an ideal by-pass route for local and through traffic. On the basis of 1927 traffic the Brook Park belt route across the Cuyahoga River Valley will at once carry a minimum of 6,600 vehicles between the west and east sides of the Cuyahoga River Valley. Approximately one-half of this traffic will use East Boulevard to the eastern part of the city and the other half will use Lee Road or parallel roads to the section east of the city. Brook Park west of the Rocky River would have served 2,700 vehicles a day had it been constructed in 1927.

5. A fifth major project involves the development of a depressed highway in the Walworth Run Valley from Clark Avenue at West Sixty-third Street, to Scranton Avenue, and via Scranton and the Eagle ramp connection at Ontario to the business center of the city. This route with its Clark Avenue connection to Lorain Avenue will afford relief to Lorain Avenue and also serve a large volume of local traffic originating in the area south of Lorain Avenue and adjacent to West Sixty-third Street.

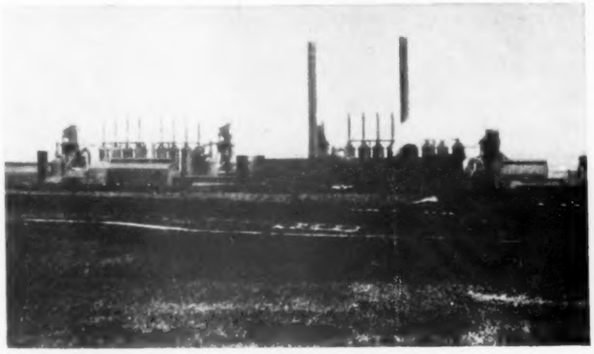
6. *Mayfield-Superior connection.*—This project proposes a direct connection from Mayfield Road at Taylor Road to Superior Road at Euclid Avenue. This connection provides a direct extension of Mayfield Road and will serve to divert part of the Mayfield Road traffic north of the badly congested sections of Euclid and Carnegie Avenues.

A Dangerous Railroad Crossing Where Separation of Grades is Planned. Note the Crosses on Right Side of Road

7. *Detroit-Hilliard connection.*—This project involves a connection using Westwood Avenue from Detroit Road to Hilliard Boulevard and Hilliard Bridge. It will divert traffic from Detroit Road and Wolf Boulevard over routes south of the Rocky River Bridge, will relieve the traffic congestion at the Rocky River Bridge, and with the lake front crossing of Rocky River will provide parallel routes north and south of this congestion point.

8. *Warrensville Center relocation.*—This project involves the development of a route east of the present location of Warrensville Center Road from Emery Road to a projection of Northfield Road south of Bedford. It will eliminate the bad approach of Northfield Road into Bedford and substitute a route without railroad crossings at grade for the present route as well as remove the main traffic route from the business sections of Bedford and Warrensville.

9. *South Miles relocation.*—This project involves a relocation of South Miles Road from Warrensville to Laing Road to improve its location, provide adequate right of way, and eliminate the badly located crossing of the Erie Railroad in Warrensville. It connects with the eastern terminus of the Brook Park belt route at Warrensville.



Industrial Development Presents Serious Obstacles in the Planning of Arterial Routes

10. *Hilliard Boulevard.*—The connection of Hilliard Boulevard with the section now under contract from Canterbury Road to the county line provides a parallel route to Center Ridge Road (United States Route 20), the most heavily traveled western approach to the city.

11. *Warrensville Center-Euclid Avenue connection.*—This project involves a direct northern connection from Warrensville Center Road to Euclid Avenue via Noble Road, Bluestone Road, and Belvoir Boulevard to a direct connection with Euclid Avenue a short distance west of the present location of Green Road. It will form a direct northerly connection to Euclid Avenue and provide a necessary link in the eastern belt-line system.

12. *Richmond-Euclid Avenue connection.*—This project involves the relocation of the Richmond-Chardon Road intersection to improve alignment and provide a direct connection to Euclid Avenue for north-south traffic, intersecting Euclid Avenue in the vicinity of Two hundred and sixtieth Street.

13. *Wolf Boulevard.*—This project forms a parallel relief route for West Lake Road to the Cuyahoga County line and, with its connections to the Spencer Road belt-line route and the Detroit-Hilliard Bridge

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connection permits traffic to cross Rocky River at either the new lake front crossing or at Hilliard Bridge.

14. *Powdermaker Road.*—This project forms a parallel relief route for West Lake Road in Lorain County connecting the proposed new high-level bridge in the city of Lorain with Detroit Road in Cuyahoga County.

In addition to these projects a number of relocations and connections between the present and proposed arterial routes are planned to connect all routes into a correlated traffic distribution system for the area.

RELIEF PROVIDED FOR CONGESTION AREAS

The proposed new routes, supplemented by the improvements planned for existing routes, provide relief for each of the serious traffic congestion areas.

1. *Superior Avenue and Euclid Avenue beyond the junction with Superior Avenue (United States Route 20).*—Relief for this area is provided by the Lake Front-St. Clair extension project, which will serve as an unobstructed direct route to the center of the city and permit greater utilization of Euclid Avenue by the large volume of local traffic produced in its immediate vicinity. A number of connections from Coit Road to Vine Street in Willoughby permit easy interchange of traffic between the two routes.

2. *Euclid Avenue and Carnegie Avenue.*—Relief for these routes is provided to the north by the Chester Avenue extension to Euclid and the Superior-Mayfield connection, and to the south by the Shaker Boulevard extension west to Broadway.

3. *Woodland Avenue.*—Relief for this route is provided by the Shaker Boulevard extension in the city and by the eastern extensions of Shaker Boulevard and South Moreland Boulevard.

4. *Broadway.*—Relief for this route is provided primarily by the Brook Park belt-line extension connecting with the Independence Road branch of the Cuyahoga Valley route at Willow.

5. *West Twenty-fifth Street.*—Relief for this route is provided to the east by the western fork of the Cuyahoga Valley arterial route, which taps all the important traffic routes from the southwest, and to the west by the proposed bridge over Big Creek in the vicinity of Brookside Park and its connection with Fulton Avenue and West Forty-fourth and West Forty-fifth Streets to a connection with Bulkley Boulevard and the new lake-front high-level crossing of the Cuyahoga River.

6. *Rocky River Bridge.*—Relief for this congestion area is provided to the north by the new lake-front crossing and to the south by the Detroit Road-Hilliard Bridge connection and the improvement of the routes from Hilliard Bridge to the center of the city.

7. *Superior high-level bridge.*—Relief for this congestion point is provided to the north by the proposed new high-level bridge and connections, in the vicinity of the present Main Street bridge, and to the south by the valley arterial route and the development and improvement of Columbus Road through the Cuyahoga Valley from its West Twenty-fifth Street and Lorain Avenue connections to St. Clair Avenue at West Ninth Street.

COST OF IMPROVEMENT PLAN SUMMARIZED

The proposed new routes not only afford adequate relief for the most serious present congestion areas and open new unobstructed arterial routes to the center of the city in the sections where such routes are badly needed but also provide necessary connections between existing routes and between existing and new routes in order to form a coordinated traffic distribution system satisfactory for present and expected future traffic. The completion of the improvement plan for present routes and the establishment and improvement of the proposed new routes and connections will provide a system of arterial, belt-line, lateral, and distributing routes which will permit traffic originating in any section of the area to move to its destination by a relatively direct and unobstructed route. The new routes are planned without railroad crossings at grade and the plan also includes the elimination of the most serious grade crossings on existing routes and protection on minor traffic routes. Provisions are also made for separation of grades at highway intersections and for circular intersections on the new routes.

After the establishment of the general location of each of the new routes was completed, a careful location reconnaissance survey was made. In each case the location established provides a feasible and practicable location for the proper development of the route.

Table 2 summarizes the approximate mileage of the plan of highway improvement, bridges to be improved, and railroad grade crossings to be eliminated.

TABLE 2.—*Summary of the 10-year plan of improvement*

Item	Cuyahoga County	Regional area exclusive of Cuyahoga County	Total
New routes to be established:	*Miles*	*Miles*	*Miles*
40-foot pavements	52.0	15.8	67.8
20-foot pavements	34.2	25.4	59.6
Total	86.2	41.2	127.4
Present highways:			
New construction—			
40-foot pavements	5.4	0	5.4
20-foot pavements	26.4	44.4	70.8
Reconstruction and widening—			
40-foot pavements	53.5	27.2	80.7
20-foot pavements	109.1	201.5	310.6
Total	194.4	273.1	467.5
Grand total	280.6	314.3	594.9
	Number	*Number*	*Number*
New bridges (exclusive of new routes) [1]	1	3	4
Replacement and widening of bridges	0	17	17
Total	1	20	21
Grade crossings to be eliminated [1]	27	28	55

[1] New bridges and grade separations on new routes are included in the estimated cost of the new routes but are not included in the number of grade crossings or bridges listed in this table.

The estimated cost of construction of the entire plan, including new routes and structures, and new construction, reconstruction, and widening on present routes, but exclusive of right-of-way acquisition and property damage costs is $63,078,000.

The summary by counties is given in Table 3.

TABLE 3.—*Total estimated construction cost*

County	Roadway	Structures	Total
Cuyahoga	$17,552,000	$23,651,000	$41,203,000
Lake	3,785,000	4,202,000	7,987,000
Lorain	3,705,000	1,204,000	4,909,000
Summit	2,322,000	1,064,000	3,386,000
Geauga	906,000	48,000	954,000
Portage	2,548,000	596,000	3,144,000
Medina	1,337,000	158,000	1,495,000
Total	32,155,000	30,923,000	[1] 63,078,000

[1] Of the above amounts the cost of new routes and structures on these new routes in Cuyahoga County is $26,300,000 and in the six adjacent counties $5,189,000.

A highway budget has been prepared for each county and the cost distributed over the 10-year period and the improvement projects are programmed in the order of their traffic importance. It is planned to provide for the continuous improvement of each route so as to make these improvements available for use in the shortest possible time, and to prevent unnecessary traffic obstruction due to the simultaneous improvement of parallel routes.

The estimated 10-year budget to provide for the total improvement plan is well within the financial ability of the several counties.

(Continued on p. 152)

FIELD EXPERIMENTS IN THE CURING OF CONCRETE PAVEMENTS

REPORT ON COOPERATIVE EXPERIMENTS CONDUCTED BY THE MARYLAND STATE ROADS COMMISSION AND THE UNITED STATES BUREAU OF PUBLIC ROADS

Reported by F. H. JACKSON, Engineer of Tests, and GEORGE WERNER, Senior Scientific Aid, Division of Tests, Bureau of Public Roads

DURING the summer of 1926 the Maryland State Roads Commission, in cooperation with the United States Bureau of Public Roads, began a series of field experiments on the Crain Highway between Baltimore and Marlboro, Md., for the purpose of obtaining data regarding the use of sodium silicate and calcium chloride as substitutes for wet earth in curing concrete pavements. This paper presents the results of all compressive and transverse strength tests which have been made in this investigation, together with a discussion of the behavior of the various test sections as indicated by crack surveys and detailed observation of surface conditions.

This series of tests is a unique field investigation so far as the authors are aware, in that compression and transverse tests were made at very early ages on specimens formed by placing the molds in large slabs cast at the side of the road so that the test specimens could be easily taken from the slabs after any desired period of curing. The testing of pavement concrete heretofore has been confined largely to tests of specimens (either beams or cylinders) cast alongside the road, or the testing of cores drilled from the completed pavement. In this case it was desired to secure data as to the early strength of the concrete, obtained from specimens cured under conditions as nearly as possible identical with the conditions under which the pavement itself was cured. The method of molding the specimens in large concrete slabs cast alongside the pavement and cured in exactly the same manner as the pavement seemed the nearest approach to this ideal condition.

The two proposed methods of curing concrete which are herein discussed have been quite actively promoted during the past few years, principally on the grounds that they are more easily controlled and at the same time are just as effective as the usual wet-earth method.

Owing to the difficulty of securing complete enforcement of the conventional specification for water curing on the avergae job, it seems advisable to investigate the efficiency of any proposed method which is obviously more easily controlled and possibly just as economical as the conventional process. Water curing requires an extensive water line, as well as an inspector, constantly on the job to see that the pavement is kept wet for the specified period, whereas in the case of the two substitute methods considered in this report, the pavement requires no attention subsequent to the initial treatment. Granting then, the desirability of these substitute methods from the standpoint of control, it remains to determine whether either or both are as efficient as the usual method and it was for the purpose of throwing light on this question that the following experiments were carried out.

TEST SECTIONS DESCRIBED

The field experiments consisted of two test sections of concrete pavement on the Crain Highway in Maryland, beginning at a point just south of its intersection with the Defense Highway at Priests Bridge. Each section was approximately 2½ miles in length and was divided into three subsections of approximately equal length, one of which was cured by means of wet earth, one by means of sodium silicate, and one by means of a calcium chloride admixture. The construction of the earth-cured and sodium silicate-cured subsections of the first test section was begun May 10 and completed June 14, 1926. The calcium chloride-cured subsection of the first test section was constructed between August 30 and September 15, 1926. The second test section, each third of which was cured by one of the three methods, was begun October 11 and finished November 13, 1926.

The test sections were laid in accordance with the standard specification requirements of the Maryland

APPLYING SODIUM SILICATE SOLUTION TO SURFACE

State Roads Commission except for the special curing features involved. The pavement was 15 feet in width, with a 6–8–6 cross section and was laid on a flat subgrade. The subgrade in general was fairly uniform, consisting essentially of a loamy sand-clay, with the exception of a short stretch of sand at the beginning of the first section. The concrete was approximately a 1:2:4 mix, field volumetric proportions, the cement factor being maintained at 6 bags per cubic yard of finished concrete. A single standard brand of Portland cement passing all requirements was used throughout. The results of physical tests on samples of this cement are given below:

Fineness, percentage retained	15.2.
Initial time of set	3 hours 40 minutes.
Final time of set	5 hours 55 minutes.
Soundness	O. K.
Normal consistency, percentage	23.8.
Tensile strength 1:3 mortar, pounds per square inch:	
At 7 days	305.
At 28 days	400.

A finely graded sand from a local pit (see second tabulation) was used in both test sections. Due to its

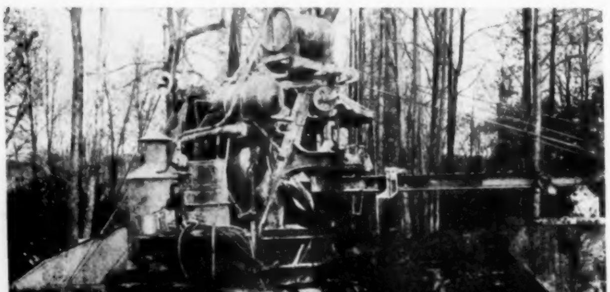
fineness, it gave a very smooth "velvety" concrete. The coarse aggregates employed in the test sections were river gravels containing about 20 per cent of crushed fragments. That used in the first section was very coarsely graded, ranging from a maximum size of about 3½ inches to one-fourth inch, with the intermediate grading varying considerably from stock pile to stock pile. The gravel in the second test section was much more uniform in grading and ran from about 2 inches down to one-fourth inch.

Mechanical analysis of sand:

Percentage retained on—	Sample A [1]	Sample B [2]	Sample C [3]
10-mesh sieve	0	0.5	0.5
20-mesh sieve	1	1.5	1.5
30-mesh sieve	8	10.5	11.5
40-mesh sieve	18	34.0	35.5
50-mesh sieve	73	82.0	79.5
100-mesh sieve	96	98.5	98.5
200-mesh sieve	97	99.5	99.5
Percentage of silt and clay	1.6	----	----

[1] Sampled and tested by Bureau of Public Roads. Tested Apr. 15, 1926.
[2] Sampled and tested by Maryland State Roads Commission. Tested May 25, 1926.
[3] Sampled and tested by Maryland State Roads Commission. Tested Sept. 3, 1926.

Finishing was done by hand in accordance with the usual practice obtaining in the State, which consists of first striking the concrete with a heavy metal template, followed by a transverse wood float and rubber belt.



Mixer Equipped with a Device Built by Contractor for Charging Each Batch with Correct Amount of Calcium Chloride Solution

CURING METHODS DESCRIBED

The method of wet-earth curing was similar to that usually employed. The concrete was covered with wet burlap as soon after finishing as possible. The burlap was subsequently sprinkled if necessary and was allowed to remain in place until the following day, when it was removed and the pavement immediately covered with 2 inches of earth. This was kept continuously wet for about 7 days and was finally removed at the end of 21 days, when the pavement was opened to traffic. As the curing on this job was constantly under the supervision of an inspector, it was perfectly done, which is not always true of the average earth-curing job.

On the sodium silicate subsection wet burlap was applied in the same manner as on the earth-cured section. The next morning it was removed and the sodium silicate applied. The manufacturer's suggestions regarding the use of sodium silicate were followed, and for this experiment a commercial 42.5° Baumé product was furnished having a nominal soda-silicate ratio of 1 to 3.25. A solution of 3 parts sodium silicate to 1 part water, was prepared by thorough mixing in a barrel. This was spread upon the concrete, and squeegeed over the surface with soft-fiber brooms. The solution was applied at the rate of 1 pound of concentrated solution to 1 square yard of pavement surface.

In the case of the subsections cured with calcium chloride, 2 pounds of 75 per cent flake calcium chloride per sack of cement were mixed integrally with the concrete, a device being used for measuring the required amount of calcium chloride solution and charging it into the mixer at the time the water was added. Wet burlap was applied to the finished surface as soon as possible, and removed the following day. No further curing treatment was given.

TEST SLABS CONSTRUCTED UNDER CONDITIONS SIMILAR TO THOSE OF ROAD SURFACE

Slabs were constructed at intervals along the road and about 3 feet from the edge of the pavement. These slabs were for the purpose of casting test cylinders from which strength data could be obtained at early periods. This was considered more practical than casting cylinders in the road slab proper, which would have required a great deal of care to prevent displacement of the molds when the concrete was discharged from the mixer, and would probably have interfered with the progress of the work. Cores could also be conveniently drilled from the test slabs cast in this manner. Each slab was cured in exactly the same manner as the adjacent pavement. Seven slabs were cast for each subsection, with the exception of the calcium-chloride and wet-earth subsections of the second test section where only five slabs were cast in each case.

The test slabs on the first section were 3 by 12 feet by 8 inches deep. Before filling the wooden forms for a slab, the subgrade was tamped and wetted, then finished to a constant depth of 8 inches. Six cylinders were cast in each test slab. The molds for test cylinders consisted of two parts: An inner slotted wrought-iron shell having an inside diameter of approximately 6 inches, a length of 8 inches and a shell thickness of one-quarter inch, and an outer loosely-fitting, galvanized, 20-gauge sheet metal shell 10 inches in length. After assembling the two parts of the molds, they were placed upright on the subgrade within the forms and approximately on the longitudinal center line of the test slab. The top of the inner shell was placed one-quarter inch below the level of the top of the forms and one-half inch above the top of the sheet metal shell which was driven about 2¾ inches into the subgrade. A coating of heavy grease between the two molds facilitated removal of the iron cylinder and a layer of grease at the top of the outer mold sealed the space between the two, preventing any leakage of mortar which would have made removal difficult. Slots at the top of the iron mold made possible its removal by chiseling through the one-half inch layer of concrete and then prying it out with two pinch bars bent at an angle of 45°. One person could remove these molds without difficulty.

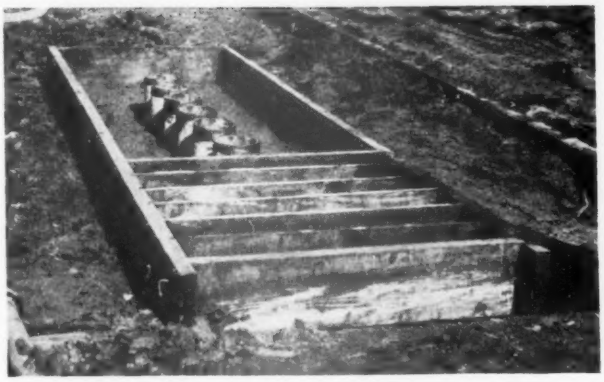
The slab forms for the second test section had the same inside dimensions as those on the first, but, in addition to the 6 cylinders, beams 6 by 6 by 36 inches were formed by using transverse spacers. To get the desired depth of beam it was necessary to place in the bottom of the

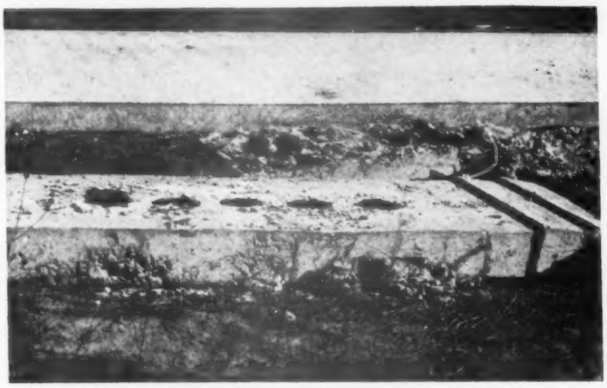
form 2 inches of earth which was compacted and smoothed so as to give a smooth surface on the bottom of the beams. All cylinders and beams for test within 30 days were cast in the test slabs. Cores 6 inches in diameter were drilled from the test slabs for all tests at later periods.

Concrete was discharged directly from the paving bucket into the form. Usually two ½-cubic-yard buckets or one 1-cubic-yard bucket gave enough concrete to fill the slab form with a small excess which was shoveled back into the road.

Two methods of filling the cylinder molds were used. On the first section the molds were filled in two layers, each layer being rodded 25 times. Those of the second section were filled in one operation, and rodded 25 times. This was found to be sufficient as excess rodding pushed the coarse aggregate to the bottom of the cylinder and brought excess mortar to the top. The beams made on the second section were formed in two layers, each layer being rodded 25 times. This was done to prevent honeycombing.

An attempt was made to make the consistency of each test slab the same as the average of the day's run. However, as the consistency of the concrete on this job varied through quite a wide range, as shown by hourly slump tests, this result could not be satisfactorily attained. Variation in moisture content of the fine and coarse aggregate, as well as variation in grading of the coarse aggregates, partly explain this range in consistency. Faulty water valves on the mixer also contributed to the difficulty of obtaining a uniform consistency. These variations in consistency are indicated in Table 1.





ARRANGEMENT FOR CASTING TEST BEAMS AND BEAMS AND SLAB AFTER REMOVAL OF FORMS

TABLE 1.—*Results of slump tests for consistency on test slabs*

Slab No.	Slumps recorded on first section	Slumps recorded on second section	Slab No.	Slumps recorded on first section	Slumps recorded on second section
	Inches	*Inches*		*Inches*	*Inches*
1	8	5	12	5	4
2	8	½	13	3	2
3	8	5	14	5	5
4	4	5	15	6	5
5	5	5	16	4	5
6	4	8	17	7	6
7	6	6	18	8	----------
8	3	5	19	5	----------
9	7	7	20	4	----------
10	5	4	21	5	----------
11	5	6			

Each slab was struck off with a 2 by 4 inch plank 5 feet long. The surface was finished by hand floating, care being taken to prevent an excess of fine material working to the top. A smooth surface was thus obtained on the beams and the location of each cylinder could be seen by the circle in the concrete above each mold.

The date upon which each slab was cast, the curing method used and the temperature and precipitation record for the date of casting and for three days immediately following, are given in Table 2. It was felt that a temperature and rainfall record was necessary, due to the possible effect of such variables on the early strength of the concrete.

All specimens were transported to the laboratory for testing, a distance of about 25 miles. This caused a delay in testing in a few cases of from 18 to 36 hours. While in transit the specimens were wrapped in wet burlap to prevent drying out. Cylinders were left in their molds until ready for testing.

REMOVING CYLINDERS FROM TEST SLAB

Each beam was tested in cross bending as a cantilever, the top of the beam (as cast in the slab) being in tension. Two breaks were made on each beam, the cross section and overhang being accurately measured. Each beam was bedded in plaster of Paris to obtain a plane bearing on the bottom.

RESULTS OF CYLINDER AND BEAM TESTS DISCUSSED

Results of compression tests of cylinders which were made at various ages up to 29 days are given in Table 3, while Table 4 gives the results of the transverse strength tests. These data, in general, indicate very little difference in the average strength of the concrete

TABLE 2.—*Temperature and precipitation records for each test slab*

FIRST SECTION

Slab No.	Date laid	Method of curing	Average temperature following construction				Total precipitation following construction			
			Date laid	First day after	Second day after	Third day after	Date laid	First day after	Second day after	Third day after
	1926		°F.	°F.	°F.	°F.	Inches	Inches	Inches	Inches
1	May 11	Wet earth	57	54	63	66	......	......	......	0.32
2	May 14	do	66	63	62	60	0.32	......	1.52	......
3	May 17	do	60	70	73	70	......	......	.07	......
4	May 19	do	73	70	59	63	.07	......	......	.02
5	May 21	do	59	63	62	54	......	0.02	.11	.02
6	May 25	do	60	59	60	60	......	......	......	......
7	May 26	do	59	60	60	55	......	......	......	......
8	May 28	Sodium silicate	60	55	60	72	......	......	......	......
9	June 2	do	68	72	56	51	......	......	.32	.17
10	June 8	do	65	68	65	67	.08	......	......	......
11	June 9	do	68	65	67	75	......	......	......	.17
12	June 10	do	65	67	75	75	......	......	.17	......
13	June 11	do	67	75	75	79	......	.17	......	.09
14	June 14	do	79	75	68	57	.09	.05	......	......
15	Aug. 31	Calcium chloride (integral)	65	67	78	68	......	......	......	1.18
16	Sept. 1	do	67	78	68	64	......	......	1.18	.02
17	Sept. 8	do	68	75	75	60	......	......	1.03	......
18	Sept. 9	do	75	75	60	64	......	1.03	......	......
19	Sept. 10	do	75	60	64	70	1.03	......	......	......
20	Sept. 13	do	70	63	63	69	......	......	......	......
21	Sept. 15	do	63	69	71	68	......	......	......	......

SECOND SECTION

Slab No.	Date laid	Method of curing	Date laid	First day after	Second day after	Third day after	Date laid	First day after	Second day after	Third day after
12	Nov. 3	Wet earth	37	34	40	40	......	......	......	......
13	Nov. 4	do	34	40	40	45	......	......	......	......
14	Nov. 8	do	56	63	53	31	......	......	0.78	......
15	Nov. 9	do	63	53	31	29	......	0.78	......	......
16	Nov. 11	do	31	29	35	50	......	......	......	......
5	Oct. 18	Sodium silicate	45	52	47	45	......	......	......	......
6	Oct. 19	do	52	47	45	44	......	.24	......	......
7	Oct. 21	do	45	44	47	53	......	......	.03	0.18
8	Oct. 22	do	44	47	53	53	......	.03	.18	.67
9	Oct. 26	do	40	37	42	56	......	......	......	.02
10	Oct. 27	do	37	42	56	61	......	......	.02	......
11	Oct. 28	do	42	56	61	56	......	.02	......	.74
1	Oct. 12	Calcium chloride (integral)	61	63	62	55	......	.06	.05	......
2	Oct. 13	do	63	62	55	48	0.06	.05	......	......
3	Oct. 14	do	62	55	48	55	.05	......	......	......
4	Oct. 15	do	55	48	55	45	......	......	......	......
17	Nov. 12	do	29	35	50	59	......	......	......	.13

cured by the three methods except that on both test sections the concrete cured with calcium chloride shows somewhat higher results in compression than the concrete cured by either of the other two methods. In the first section this difference is only apparent during the first three days, whereas in the case of the second test section an increase may be observed throughout the entire period. Reference to Table 4, on the other hand, fails to show any appreciable difference in transverse strength which may be attributed to the curing method used. In this connection, however, it will be noted that no beam tests were made at periods less than four days.

In analyzing these early-age strength data, the marked variations in strength between individual specimens of the same age but cast on different days is apparent. For instance, referring to Table 3, it will be observed that the crushing strength of specimens taken from slabs Nos. 2 to 7, inclusive, of the first section, and broken at three days, varies all the way from 667 to 1,483 pounds, with an average of 1,039 pounds. Just how much of this variation is due to unavoidable errors in testing is problematical. Assuming, however, that errors from this source were no greater than is usual in testing work of this character, most of the

TABLE 3.—*Results of crushing-strength tests of cylinders cast in test slabs*

FIRST SECTION

Slab No.	Method of curing	Crushing strength in pounds per square inch at—											
		1 day	2 days	3 days	4 days	7 days	8 days	14 days	15 days	21 days	22 days	28 days	29 days
1	Wet earth	.....	1,050	.....	1,450	1,784	.....	1,853	.....	1,695	.....	.....	.....
2	do	490	.....	765	.....	.....	1,485	1,685	.....	1,498	.....	.....	.....
3	do	661	.....	1,270	.....	1,678	.....	.....	.....	1,705	.....	1,900	.....
4	do	478	.....	1,112	.....	.....	1,184	.....	.....	.....	.....	1,790	.....
5	do	483	.....	667	.....	1,564	.....	1,734	.....	1,306	.....	1,543	.....
6	do	.....	1,102	1,483	.....	.....	1,535	.....	.....	1,744	.....	.....	.....
7	do	517	.....	934	.....	1,810	.....	.....	.....	2,075	.....	2,170	.....
	Average	526	1,076	1,039	.....	1,709	1,401	1,757	.....	1,671	.....	1,851	.....
8	Sodium silicate	524	.....	.....	1,415	.....	1,710	.....	.....	1,560	.....	1,640	.....
9	do	560	.....	1,045	.....	.....	.....	1,620	.....	1,630	.....	1,590	.....
10	do	.....	.....	.....	1,410	1,555	.....	1,925	.....	1,940	.....	2,062	.....
11	do	.....	.....	1,223	.....	1,763	.....	1,825	.....	1,960	.....	1,895	.....
12	do	.....	769	.....	1,215	1,460	.....	1,215	.....	1,155	.....	1,560	.....
13	do	504	.....	1,230	.....	2,160	.....	1,950	.....	1,675	.....	1,850	.....
14	do	907	.....	.....	.....	1,908	.....	1,522	.....	1,785	.....	1,986	.....
	Average	624	.....	1,166	1,347	1,769	.....	1,676	.....	1,672	.....	1,798	.....
15	Calcium chloride	.....	723	1,090	.....	1,435	.....	1,480	.....	1,455	.....	1,565	.....
16	do	974	.....	1,750	.....	.....	.....	.....	.....	1,960	.....	2,080	.....
17	do	.....	1,275	.....	.....	.....	1,565	1,950	.....	1,690	.....	2,453	.....
18	do	.....	1,075	.....	1,015	1,470	.....	1,620	.....	1,805	.....	1,606	.....
19	do	598	.....	1,090	.....	1,325	.....	1,445	.....	1,325	.....	1,592	.....
20	do	964	.....	1,275	.....	1,925	.....	1,725	.....	2,155	.....	1,992	.....
21	do	1185	.....	1,880	.....	1,720	.....	2,230	.....	1,846	.....	2,504	.....
	Average	930	1,025	1,417	.....	1,575	.....	1,742	.....	1,742	.....	1,970	.....

SECOND SECTION

Slab No.	Method of curing												
12	Wet earth	.....	309	428	.....	.....	1,510	1,716	.....	.....	.....	.....	2,220
13	do	.....	406	.....		.....	2,246	.....	2,822	.....	2,175	.....	3,233
14	do	.....	690	.....	752	.....	1,109	.....	1,450	.....	2,225	.....	1,930
15	do	.....	580	.....	1,060	.....	1,440	.....	1,914	.....	.....	.....	1,730
16	do	.....	502	.....	.....	.....	2,035	.....	1,752	.....	2,470	2,160	.....
	Average	.....	497	.....	906	.....	1,668	.....	1,984	.....	2,290	.....	2,279
5	Sodium silicate	610	.....	.....	956	.....	1,169	1,831	.....	.....	2,029	.....	2,436
6	do	322	.....	.....	1,150	.....	1,776	1,461	.....	.....	2,262	.....	1,802
7	do	.....	469	.....	.....	1,130	.....	.....	1,904	.....	2,072	.....	2,503
8	do	781	.....	.....	1,105	.....	1,759	.....	1,970	.....	2,552	.....	2,485
9	do	.....	398	.....	874	1,980	.....	.....	2,000	.....	2,805	.....	2,457
10	do	145	.....	730	.....	1,757	.....	.....	2,237	2,450	.....	.....	.....
11	do	.....	461	.....	875	.....	1,342	.....	2,091	.....	2,664	.....	2,141
	Average	465	443	.....	992	1,622	1,512	1,646	2,040	.....	2,397	.....	2,302
1	Calcium chloride	546	.....	.....	1,340	1,365	.....	.....	1,780	1,990	.....	2,170	.....
2	do	.....	1,510	2,000	.....	2,035	.....	.....	2,740	3,100	.....	.....	3,550
3	do	.....	1,090	.....	1,950	.....	1,940	1,950	.....	2,880	.....	2,620	.....
4	do	831	.....	1,919	.....	.....	2,442	.....	2,492	.....	2,294	.....	3,598
17	do	242	.....	.....	1,362	.....	1,992	1,744	.....		.....	2,610	.....
	Average	540	1,300	1,960	1,551	1,700	2,125	1,847	2,337	2,657	.....	2,467	3,574

variations in strength may be attributed to variations in the quality of the concrete.

For concrete of the character placed on this job and assuming a constant cement factor from day to day, there are two principal factors which might account for these differences: (1) Variations in temperature and humidity conditions during and immediately subsequent to placing; and (2) variations in the water content of the concrete. Table 1 gives the consistency as indicated by the slump of the concrete which was used in the fabrication of each test slab and Table 2 indicates the variations in temperature and rainfall. As stated previously, it was found impossible to satisfactorily control the water content, owing to the use of inadequate water-measuring devices on the mixers and leaky valves. The slump-test values will, therefore, have to serve as the best available indication of water content.

Table 4.—*Results of transverse strength tests of beams cast in test slabs of second section*

Slab No.	Method of curing	Modulus of rupture in pounds per square inch at—							
		4 days	5 days	7 days	8 days	14 days	15 days	28 days	29 days
12	Wet earth				368	410			485
13	do		385		454		587		554
14	do	321			481		480		491
15	do	267			367		486		454
16	do		336		515		544		580
	Average	294	360		437		524		513
5	Sodium silicate	293			444	480			578
6	do	362			358	485			566
7	do		335	377			497		602
8	do	369			430		522		631
9	do	260		329			439		553
10	do			405			530		
11	do	309			378		436		499
	Average	319		370	403	483	485		572
1	Calcium chloride	308			385		515	419	
2	do		323	347			398		515
3	do		329		403	418		534	
4	do	391			375		518		539
17	do	406			445		480	404	
	Average	368	326		402		478	452	527

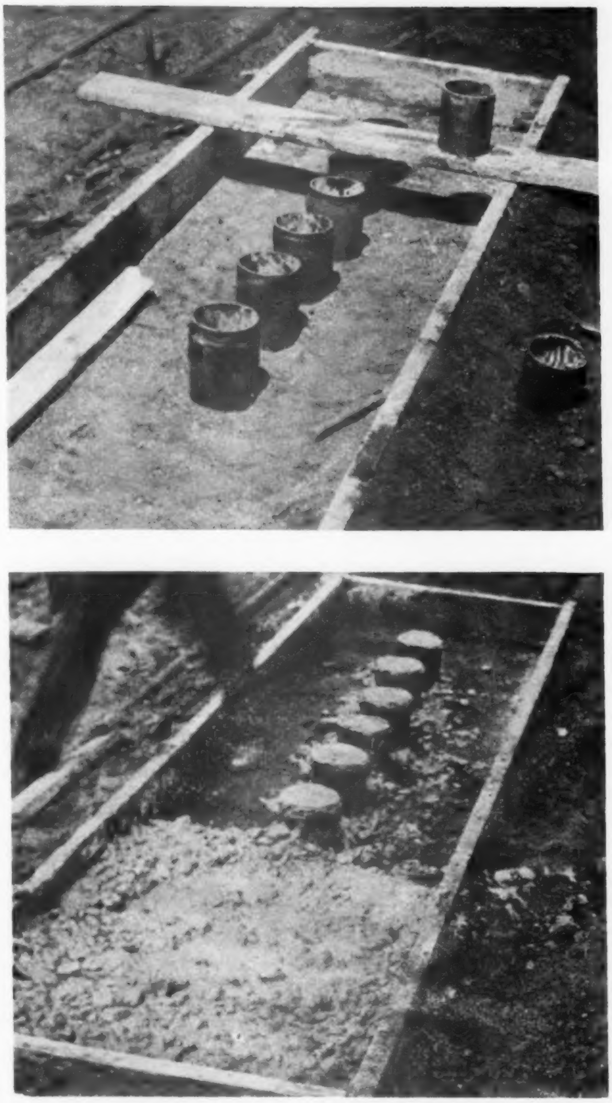
Comparing the individual test results given in Table 3 with the corresponding temperature and rainfall data shown in Table 2, it will be seen that, except in one or two extreme cases such as low strength at one day on slab 17 of the second section which is associated with low temperatures, there is no consistent relation between strength and either of these factors. It is apparent that variations in temperature are either not effective or they are overshadowed by more important variables such as the water content of the concrete.

When materials for concrete pavements are measured by loose volume, as in this case, it is inevitable that rather marked fluctuations in water content of the concrete will occur from day to day owing to changes in the moisture content of the sand and fluctuations in the grading of the coarse aggregates. On the first section of these tests marked variations in grading of coarse aggregate occurred, making the control of water very difficult.

A comparison of the strength data with the results of the slump tests, however, indicates either that water content was not a controlling factor in determining strength or that the slump test can not be taken as an accurate measure of the amount of water in the concrete. The importance of water in determining strength has been demonstrated many times through carefully controlled laboratory tests. On the other hand, it has not been established that the slump test gives anything more than a rough indication of the consistency of the concrete. In the opinions of the authors, the principal variations in strength shown in this report are due to variations in the water content of the concrete, and this would have been indicated by accurate measurements of the water actually used in the various batches had it been possible to make them.

CORES FROM TEST SLABS INDICATE PRACTICALLY SAME STRENGTH FOR THE THREE METHODS OF CURING

The results of compression tests of cores drilled from the test slabs, which are given in Tables 5 and 6, and the average values, which are plotted in Figure 1, fail to reveal any consistent advantage for any of the curing methods. It is true that in the first section the 28-day and 4-month test values are considerably higher for the concrete cured with wet earth than in the case of the other two methods. Averages for this section at six months are close together. At one year there is so little difference that it appears safe to say that under the conditions prevailing the three methods give essentially the same strength results. Practically the same thing may be said of the six-month and one-year tests on the second section, although the wet-earth results are somewhat low, particularly at the one-year period.



Illustrating Arrangement for Casting Test Slabs and Cylinders

Comparing the results of core tests at 28 days with the results of tests on the cast cylinders from the same slabs and at the same age, it will be observed that the test values for cores are consistently much higher. In general, some difference in favor of drilled cores is to be expected, but the values determined are somewhat unusual. There are two testing conditions, however, which may account for this variation.

TABLE 5.—*Results of crushing-strength tests of cores drilled from test slabs of first section*

Slab No.	Method of curing	Crushing strength in pounds per square inch at—			
		28 days	4 months	6 months	1 year
1	Wet earth			4, 620	4, 485
2	do	3, 260	4, 485		4, 340
3	do	3, 700	4, 140	4, 510	4, 335
4	do	3, 830	4, 550	3, 180	4, 570
5	do	3, 995	3, 830	4, 060	4, 310
6	do	4, 320	4, 260	3, 630	4, 770
7	do	3, 850	4, 575	4, 435	4, 585
	Average	3, 825	4, 305	4, 405	4, 485
8	Sodium silicate	3, 560	3, 580	4, 560	4, 685
9	do	4, 010	3, 850	4, 670	4, 560
10	do	3, 280	4, 120	3, 785	4, 610
11	do	3, 620	3, 935	4, 950	4, 140
12	do	3, 080	3, 430	3, 925	4, 210
13	do	2, 980	3, 810	4, 140	4, 490
14	do	3, 280	3, 620	3, 450	4, 150
	Average	3, 400	3, 765	4, 210	4, 406
15	Calcium chloride	3, 095	[1] 3, 040	4, 027	4, 694
16	do	3, 960	[1] 4, 075	4, 635	4, 415
17	do	3, 085	[1] 3, 350	4, 346	4, 112
18	do	2, 985	[1] 4, 085	4, 247	3, 986
19	do	3, 135	[1] 3, 635	4, 542	4, 432
20	do	2, 450	[1] 3, 720	4, 480	5, 198
21	do	3, 085	[1] 3, 525	3, 958	3, 581
	Average	3, 115	3, 635	4, 323	4, 345

[1] Age at test, 3 months.

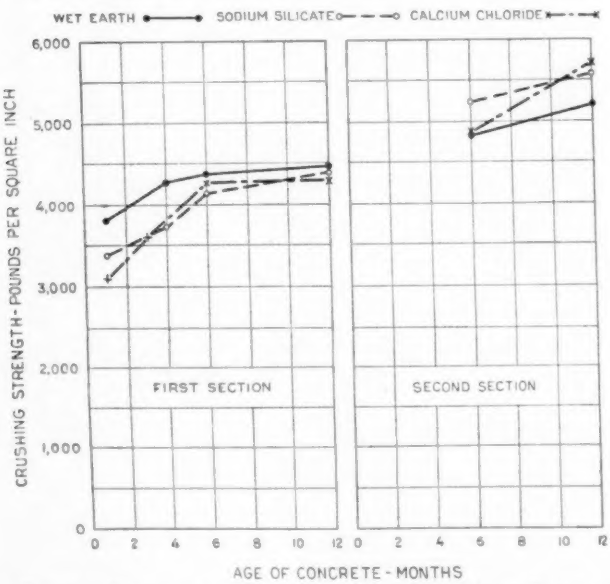


FIG. 1.—RESULTS OF COMPRESSION TESTS OF CORES DRILLED FROM TEST SLABS

All of the cast cylinders were capped with plaster of Paris prior to testing (since they were to be tested as soon as possible after receipt in the laboratory), whereas neat cement was used for the cores. It is well known that, except at very early ages, concrete specimens capped with plaster are apt to run lower in strength than when capped with cement. In addition, the cores were tested dry, whereas the cylinders were in a damp condition when tested. However, the fact that different methods of capping were used makes it necessary to consider the two groups of tests independently, irrespective of the reasons for wide variations. Fortunately the value of each group as indicating variations in strength due to the method of curing is not impaired, although, as just stated, results in one group should not be compared with those in the other.

TABLE 6.—*Result of crushing-strength tests of cores drilled from test slabs of second section*

Slab No.	Method of curing	Crushing strength in pounds per square inch at—		
		(See note)	6 months	1 year
12	Wet earth	3, 633 (105)	4, 441	4, 615
13	do	5, 930 (137)	5, 389	5, 748
14	do	4, 993 (161)	3, 917	4, 878
15	do	4, 927 (160)	4, 953	5, 166
16	do		5, 573	5, 779
	Average		4, 855	5, 237
5	Sodium silicate	4, 875 (98)	5, 020	5, 441
6	do	5, 167 (97)	5, 440	6, 452
7	do	5, 092 (118)	5, 401	5, 065
8	do	5, 334 (117)	5, 554	6, 070
9	do	5, 067 (113)	5, 558	5, 517
10	do	4, 826 (112)	5, 286	4, 803
11	do	4, 242 (111)	5, 287	5, 882
	Average		5, 364	5, 604
1	Calcium chloride	3, 701 (99)	4, 077	5, 759
2	do	4, 975 (98)	5, 200	6, 096
3	do	4, 639 (97)	5, 242	6, 461
4	do	4, 727 (101)	5, 275	5, 232
17	do	5, 050 (157)	4, 672	5, 221
	Average		4, 893	5, 754

NOTE.—Figures in parenthesis give age in days at test.

CORES DRILLED FROM PAVEMENT SUBSTANTIATE CONCLUSIONS

Table 7 gives the results of compression tests on cores cut from the pavement and tested at the University of Maryland under the direction of A. N. Johnson. These tests were confined to the first experimental section. The apparent reversal in relative rating of the wet earth and sodium silicate concrete between 90 days and 1 year is not considered significant in view of

TABLE 7.—*Results of crushing strength tests of cores drilled from pavement (first section) and tested at University of Maryland*

Method of curing	Crushing strength in pounds per square inch at—						
	28 days		90 days		(See note)		
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 3
Wet earth	3, 800	3, 600	3, 380		4, 040	4, 260	
Do	3, 220	3, 610	3, 350	3, 080	3, 410		
Do	3, 280		3, 350	2, 995	3, 980		
Do	2, 390	2, 530	3, 555	2, 795			
Do	2, 790	3, 440		3, 240			
Do	3, 060	2, 960	2, 935	3, 390			
Average	3, 090	3, 245	3, 315	3, 100			
General average	3, 170		3, 205		3, 920		
Sodium silicate	3, 450	2, 720	3, 235	3, 800	3, 320	3, 175	4, 100
Do	3, 410	2, 840	3, 290	4, 400	3, 770	3, 065	2, 910
Do	3, 200	3, 030		4, 070	2, 640	2, 790	4, 510
Do	2, 680		4, 035	3, 795	3, 520		
Do		3, 390	4, 090	4, 760			
Do		3, 040	3, 340	3, 960			
Average	3, 185	3, 005	3, 600	4, 130			
General average	3, 095		3, 865		3, 380		
Calcium chloride	3, 035	2, 765	3, 425		3, 495	2, 840	2, 520
Do	3, 475	2, 295	3, 150		3, 910		3, 585
Do	3, 256	2, 835	2, 960		4, 190		2, 060
Do	2, 645	2, 745	3, 280				
Do	2, 610	3, 200	2, 900				
Do	3, 020	2, 470	2, 540				
Average	3, 005	3, 720	3, 045				
General average	2, 865		3, 045		3, 230		

NOTE.—Cores drilled in June, 1927. Concrete in the wet earth and sodium silicate sections approximately 1 year old; concrete in the calcium chloride sections approximately 10 months old.

the relatively small number of test specimens involved. The tests may be considered as substantiating in general the conclusion that, in so far as strength is concerned, the three methods of curing give essentially the same results.

SURVEY SHOWS EXTENT OF CRACKING ON VARIOUS SECTIONS

Table 8 gives the results of a crack survey of the pavement made on January 6, 1928. With the exception of the wet-earth subsection of section 1, the average spacing of transverse cracks is about the same for all methods of curing. It is interesting to compare these values with those obtained on the two subsections of the first test section as a result of a survey made about a month after the section had been laid. This earlier survey showed an average spacing of 100 feet for the earth-cured section and 77 feet for the sodium silicate-cured section, as compared with 88 feet and 63, respectively, at a later date.

TABLE 8.—*Results of condition survey of test sections made on January 6, 1928*

Section No.	Method of curing	Length of section	Number of transverse cracks and joints	Slab length		
				Average	Maximum	Minimum
		Feet		*Feet*	*Feet*	*Feet*
1	Wet earth	4,404	50	88	208	20
	Sodium silicate	4,253	68	63	165	5
	Calcium chloride	4,248	75	57	133	4
2	Wet earth	3,449	80	43	155	6
	Sodium silicate	4,280	76	56	139	5
	Calcium chloride	5,540	101	55	212	4

It will be seen that most of the transverse cracking which has occurred (that is, in about a year and a half) took place within a few weeks after construction. The data available does not indicate any particular reason why the earth-cured subsection on the first test section should have developed such a small number of cracks as compared with the corresponding portion of the second test section. It may be that a detailed subgrade survey of this pavement will furnish a clue, and it is expected that such a survey will be made shortly. In view of the large number of cracks on the second wet-earth-cured section, however, as compared with sections cured by the other methods, it appears reasonable to assume that the wide spacing on the first wet-earth-cured section was due to some cause other than the method of curing—possibly the subgrade. It may be said in this connection that the water curing on the second test section was fully as thorough and efficient as on the first.

SURFACE INDICATIONS REPORTED

The present condition of the surface of each of the test sections, in so far as they may have been affected by the curing method, is of interest. In the case of the first test section the earth-cured subsection shows probably fewer surface defects than either of the other two.

There is considerable thin surface scale on the first sodium-silicate section, which appeared a few days after the construction of the pavement and which has apparently progressed very little beyond the initial stage. This scale has been attributed to excess water on the burlap cover, caused probably by sudden showers during construction. It is confined largely to sections constructed on days when it was necessary to shut down because of rain. This surface scale does not appear on the second sodium silicate section, which was cured in exactly the same manner as the first section, which leads to the assumption that, whatever the cause it was probably not due to the silicate.

Both of the calcium-chloride sections show considerable surface wear and scale. In spots the thin mortar surface which remained after finishing has worn completely away. This condition is believed to be due to difficulties encountered by a crew inexperienced in the use of concrete containing a calcium chloride admixture. The reworking of a surface which had slightly stiffened up might conceivably produce a thin weak top which would readily scale off under traffic, producing a rather unsightly surface. It is not felt that this condition should be construed as a general indictment of the use of calcium chloride as an admixture because it is well known that with experienced crews excellent pavements, in so far as surface conditions are concerned, may be produced.

CONCLUSIONS

As far as can be judged by strength tests up to and including one year, as well as by a study of the number and distribution of cracks up to the present time, it appears that under the conditions obtaining on this job either of the two proposed methods of curing concrete pavements covered by this study might be used in place of the wet-earth method.

It must be remembered, however, that the final answer to such a question as this can not be given until the various sections have been subjected to a sufficient number of seasonal changes to bring out any differences which may exist as to their comparative resistance to weathering. This is somewhat intangible, but none the less important, property of concrete for pavements and is one upon which its final service value largely depends.

How does this curing process affect the density or permeability of the concrete? This is an important question from the standpoint of resistance to frost action. It has been claimed that permeability can largely be controlled by thorough curing, the theory being that the void spaces remaining in concrete after it has hardened were originally filled with water; that a certain proportion of this water combines with the cement to form the complex hydration products resulting from the setting of cement, while the remainder evaporates leaving air voids. According to this theory, the function of curing is to keep the concrete from drying out until the maximum proportions of the total water originally used in mixing has combined with the cement. It is obvious that the higher this proportion of combined water, the lower will be the proportion of free water remaining, and consequently the lower will be the percentage of voids. The extent to which this theory applies to the curing of pavements is problematical. It is recognized, however, that the ultimate service value of the structure is dependent upon other factors besides strength, and that the effect of these factors upon the life of the pavement must be ascertained before giving unqualified indorsement to the special curing methods under consideration.

RELATION BETWEEN THE STANDARD ABRASION TESTS FOR STONE AND GRAVEL

Reported by D. O. WOOLF, Assistant Materials Engineer, Division of Tests, United States Bureau of Public Roads

THE majority of the State highway departments in their specifications for concrete permit the use of either crushed stone or gravel as aggregate and give certain requirements for each material in an attempt to obtain materials of comparable quality. The quality requirement most frequently mentioned is the percentage of wear as determined by the Deval abrasion test. It has frequently been stated that a stone with a percentage of wear of 5 is of the same quality as a gravel with a percentage of wear of 15 when considered as aggregate for concrete. In other words, the abrasion loss of stone of a given quality is only about one-third the abrasion loss of gravel of the same quality. There are, however, very little data available with which the above relation may be established.

To obtain information on this important subject a series of tests was begun in the early part of 1926. A sample of rock was tested by the standard method, and then the standard gravel abrasion test was made on rounded particles prepared from the same rock sample. Several such tests were made on rock received as routine samples, the rounded particles being prepared in the Deval abrasion machine. The results of these tests are shown in Table 1.

TABLE 1.—*Abrasion tests on rock and synthetic gravel*

Source of rock	Material	Percentage of wear, standard test	Synthetic gravel	
			Percentage of wear	Ratio to standard test
Indiana	Limestone	[1] 11.7	[2] 5.5	0.47
Virginia	Granite	[3] 2.6	[2] 2.7	1.04
Pennsylvania	Sandstone	[3] 5.8	[2] 1.4	.24
Ohio	Dolomite	[2] 11.0	[2] 13.7	1.24
West Virginia	Limestone	[3] 4.0	[3] 6.9	1.72

[1] Average of 2 tests. [2] Average of 4 or more tests. [3] Only 1 test.

ABRASION TESTS ON ROCK AND SYNTHETIC GRAVEL YIELD UNEXPECTED RESULTS

In the summer of 1927 the use of the brick rattler machine to round off rock particles into gravel shape was suggested. This proved to be a satisfactory method, and 13 large samples of crushed and solid rock were obtained for test. The physical characteristics of these rocks as determined by routine tests are shown in Table 2.

In the instructions regarding sampling it was requested that the ledge rock submitted be taken from the material being supplied to the crusher. This, it was believed, would tend toward obtaining both solid and crushed rock of the same quality. In all cases it was stated that the ledge rock had been so selected.

The material obtained furnished an opportunity to investigate also the effect of using crushed rock instead of hand-broken pieces in the standard abrasion test. It is known that the crushed material is sometimes used in the standard abrasion test in spite of the test specifications, which definitely state that only hand-broken particles shall be used. It is also frequently desirable to test crushed rock sampled from stock piles on the job to obtain some idea of its quality, and it was believed that this phase of the investigation should be considered.

A SAMPLE OF CRUSHED STONE AND SIMILAR STONE CONVERTED INTO SYNTHETIC GRAVEL

TABLE 2.—*Physical characteristics of rock as determined by routine tests*

Identification No.	Location	Name of material	Specific gravity	Absorption	Percentage of wear	Hardness	Toughness
				Per cent			
1	Ohio	Dolomite	2.63	1.82	7.4	8.3	5
2	West Virginia	do	2.84	.15	4.5	14.7	11
3	Ohio	do	2.72	.97	4.7	17.0	8
4	New York	Dolomitic marble	2.76	.08	4.9	18.0	7
5	Ohio	Dolomite	2.54	2.54	6.1	7.0	4
6	do	Limestone	2.53	2.08	8.1	.7	4
7	do	Dolomite	2.42	2.80	19.7	[1]	3
8	do	do	2.49	2.84	4.1	15.3	14
9	Texas	Limestone	2.43	1.69	8.7	2.7	4
10	Ohio	Dolomite	2.73	.70	6.3	9.7	6
11	Texas	Limestone	2.71	.17	4.4	14.7	5
12	Kansas	Argillaceous limestone.	2.49	2.52	7.0	11.3	4
13	do	Limestone	2.29	5.26	8.9	.0	4

[1] Specimens satisfactory for this test were not obtained.

Upon receipt of the samples, abrasion tests were made by three methods:

1. Standard method for rock, using cubical pieces broken by hand from ledge rock.[1]
2. As above, except that crushed rock was used.
3. Standard method for gravel, using particles of rock artificially rounded into gravel shape.[2]

In the tests made with crushed rock, samples containing 50 pieces of approximately constant size and weighing 5,000 grams were used. The results of these tests are shown in Table 3 and are summarized in Table 4. A few tests of the same character have also been made on samples submitted for routine examinations. The results are shown in Table 5.

[1] A. A. S. H. O., Tentative Standard Method No. 3, U. S. D. A. Bulletin No. 1216, revised (now in course of publication).
[2] A. A. S. H. O., Tentative Standard Method No. 4, U. S. D. A. Bulletin No. 1216, revised (now in course of publication).

TABLE 3.—*Abrasion tests of rock and synthetic gravel*

Identification No.	Material	Location	Percentage of wear		
			Standard	Standard crushed	Gravel rounded
			7.4	6.6	4.6
			7.0	6.9	3.6
1	Dolomite	Ohio	7.6	7.3	3.9
			7.3	7.1	4.1
			7.6	6.5	4.0
			4.2	4.3	2.1
			4.4	4.2	2.2
2	do	West Virginia	4.4	4.2	1.8
			4.7	4.4	1.5
			4.6	4.1	1.4
			4.6	3.5	1.4
			5.0	3.5	1.7
3	do	Ohio	4.6	4.0	1.4
			4.4	4.2	1.6
			4.8	3.8	1.8
			5.4	4.4	3.3
			5.0	4.4	3.1
4	Dolomitic marble	New York	4.7	4.2	2.3
			4.7	4.4	
			4.8	4.6	
			5.9	5.6	4.7
			6.2	6.2	5.2
5	Dolomite	Ohio	5.7	7.2	5.4
			6.8	6.3	4.2
			6.0	6.7	
			7.6	7.6	23.4
			8.4	7.1	24.2
6	Limestone	do	8.0	7.3	20.1
			9.0	7.8	22.0
			7.6	7.7	23.1
			20.1	14.6	15.6
			19.5	14.5	12.8
7	Dolomite	do	20.3	17.0	12.9
			19.1	13.0	
			19.7	15.0	
			4.6	4.0	3.4
			3.7	4.4	3.5
8	do	do	4.0	3.7	3.6
			3.9	4.0	3.2
			4.1	4.5	3.4
			8.4	10.6	7.2
			8.8	12.8	6.6
9	Limestone	Texas	9.2	13.7	4.6
			8.9	9.4	5.8
			8.1	10.1	5.0
					6.7
			6.2	6.2	
			7.0	6.2	
10	Dolomite	Ohio	6.0	5.9	
			6.2	6.2	
			5.9	6.1	
			4.2	4.0	1.4
			4.4	4.0	1.7
11	Limestone	Texas	4.4	3.7	2.2
			4.3	3.7	1.3
			4.6	3.5	1.9
			7.5	6.4	7.8
			7.2	6.1	7.8
12	Argillaceous limestone	Kansas	7.1	6.0	7.3
			6.4	6.4	7.0
			7.0	6.3	8.5
			9.5	8.0	7.2
			9.6	7.3	7.4
13	Limestone	do	10.0		6.1
			7.0		8.2
			8.6		7.4

TABLE 4.—*Average results of the abrasion tests using the three methods of testing*

Identification No.	Percentage of wear, standard test	Test of crushed rock		Gravel rounded	
		Percentage of wear	Ratio to standard test	Percentage of wear	Ratio to standard test
1	7.4	6.9	0.93	4.0	0.54
2	4.5	4.2	.93	1.8	.40
3	4.7	3.8	.81	1.6	.34
4	4.9	4.4	.90	2.9	.59
5	6.1	6.4	1.05	4.9	.80
6	8.1	7.5	.93	22.6	2.79
7	19.7	14.8	.75	13.8	.70
8	4.1	4.1	1.00	3.4	.83
9	8.7	11.3	1.30	6.0	.69
10	6.3	6.1	.97		
11	4.4	3.8	.86	1.7	.39
12	7.0	6.2	.89	7.7	1.10
13	8.9	7.6	.85	7.3	.82

TABLE 5.—*Comparison of abrasion tests of rock using hand-broken and crushed fragments*

Material	Location	Hand-broken rock, percentage of wear	Crushed rock	
			Percentage of wear	Ratio to standard test
Siliceous dolomite	Maryland	4.2	2.7	0.64
Do	West Virginia	5.6	4.0	.71
Serpentine	Maryland	4.5	3.8	.84

Following the above tests, samples of from 100 to 150 pounds of graded crushed rock were placed in the brick rattler with an abrasive charge of 200 pounds of ½-inch and 1-inch steel cubes and the machine run until inspection showed that the crushed rock had worn into the semblance of gravel. The rounded material was then tested as specified for the standard abrasion test for gravel. The results of these tests are also shown in Tables 3 and 4.

In comparing the results secured with the rock and gravel abrasion tests a very unexpected relation is presented. It has previously been stated that the general assumption regarding the ratio between the percentages of wear for the abrasion tests of rock and gravel is 1 to 3. The tests reported in this paper show that when a given material of uniform composition is tested by both the rock and gravel abrasion methods the ratio of 1 to 3 is found to be the exception rather than the rule, and that the average ratio as determined by these tests is 1 to 0.86. In other words, with the materials used the loss in the gravel abrasion test is only 86 per cent of that in the rock test.

All of the test results, with one exception, show this general relation, the one exception being sample 6, which gives a ratio of almost 1 to 3. It is possible that this material is less resistant to impact than is shown by the results of routine tests. (Table 2.) A number of rounded particles of samples 6, 12, and 13, which have the same toughness as determined by the routine tests, were tested for resistance to impact with the apparatus devised by F. H. Jackson for testing soft pieces of gravel.[3] The results are shown in Table 6. The reason for the high ratio for sample 6 may be found in the lower resistance to impact of the smaller particles.

RESULTS INDICATE DESIRABILITY OF MODIFYING OR SUPPLANTING ABRASION TEST FOR GRAVEL

It should be noted that the materials used in these tests were of uniform composition. The results are therefore applicable only to such materials.

The average natural gravel, especially that of glacial origin, is not of uniform composition, and the relation found by the above tests can not be applied to tests of this type of gravel. This nonuniformity in the average gravel emphasizes a fundamental weakness in the gravel abrasion test and raises a question as to the suitability of such a test.

Two samples with the same percentage of wear may vary widely in their suitability for use as a concrete aggregate. A gravel of reasonably uniform quality is more acceptable as an aggregate than another gravel composed of fragments which individually show a wide range in resistance to wear but with the same average

(Continued on p. 152)

[3] See Am. Soc. for Testing Materials Proc., vol. 22, pt. 2, p. 362.

STRENGTH CHARACTERISTICS OF CONCRETE AS INDICATED BY CORE TESTS

RESULTS OF COMPRESSION TESTS ON CORES DRILLED FROM MARYLAND HIGHWAYS ANALYZED

By A. N. JOHNSON, Dean of Engineering College, University of Maryland [1]

A NUMBER of investigations dealing with the general subject of strength characteristics of concrete have been carried on intermittently during the past six or seven years at the University of Maryland. These investigations were made through the cooperation of the Engineering Experiment Station of the University of Maryland, the United States Bureau of Public Roads, and the Maryland State Roads Commission. This is the first report dealing with one phase of the general subject being investigated.[2]

For many years highway engineers have sought a means for obtaining information as to the strength characteristics of concrete in completed pavement structures. The only means which has been made available up to the present time is the study of tests of cylindrical cores drilled from the finished pavement.

This paper is devoted principally to the analysis of the data obtained by testing some 2,200 such cores drilled from concrete pavements of the State highway system of Maryland during the summers of 1921, 1922, 1924, and 1926.

METHOD OF DRILLING CORES DESCRIBED

The process of core drilling is generally well known, but for the benefit of those who may not be familiar with the technic of obtaining specimens by this method it will be briefly described.

In general, there are two types of drills which are satisfactory for drilling cores from pavements; that is, the diamond drill and the steel shot drill. The shot drill is more commonly used for pavement work for economic reasons. The specimens from the concrete roads of Maryland were secured with a shot drill having a steel bit with an outside diameter of 5½ inches, and an inside diameter of about 4½ inches, the actual size of the core drilled being about 4.3 inches. The drill, with proper gear for its control, was mounted on the rear of a truck which carried a small gas engine for the operation of the drill. A 200-gallon water tank, together with various tools and equipment, were also a part of the outfit of the drill truck.

The time of drilling varied from about 4 minutes per inch to 1 minute per inch, averaging approximately 1.7 minutes per inch of core drilled. The longer time was required for concrete in which flint gravel was used as an aggregate and the shorter time for concrete with limestone aggregate. The soft steel bits were renewed from time to time, the average rate of wear being about 1 inch of bit per 100 inches of concrete drilled. The amount of steel shot necessary for drilling was about 1 to 1½ pounds per core drilled.

Two men manned the truck and a good day's work (taking groups of three cores at intervals of every mile or so) was 12 to 20 cores.

The drill left a hole in the road a little over 5½ inches in diameter. After the core was drilled a concrete plug about 5 inches in diameter and 7 inches deep (a number of which were carried as a part of the drill truck equipment) was put in the hole. The bottom of the hole was first filled with rock or gravel from alongside the road and well tamped. A small amount of cement mortar was mixed (using the water in the drill hole in order to save the usually very limited water supply) and put in the hole. The plug was put into place, which forced the excess mortar to the surface, and this was struck smooth and the patch covered with moist earth. Usually a very good repair was the result. Occasionally a heavy vehicle wheel displaced a plug a small amount, but seldom with any serious injury to the road surface.

METHOD OF TESTING CORES DESCRIBED

After the cores were delivered to the laboratory the ends were cleaned and cement mortar caps were added to each end. These mortar caps consisted of a rather stiff 1:1 mixture and were of such thickness that the specimen when capped would measure 9 inches, except in those instances where the cores were too long to permit of the preparation of a specimen of that length, in which case the length of the capped specimens was made 11 inches. Cores less than 5 inches in length were not tested.

The cores were capped in the following manner: A piece of sheet metal 9 by 15 inches was first wrapped about the core, forming a sheet-metal cylinder, which was held in place against the core by two bands of iron wire twisted tightly on the outside. One end was filled with the mortar and struck. Then the other end was filled and vigorously tamped with an iron bar about 1 square inch in cross section. The mortar was then smoothed and a glass plate put on. The specimen was then reversed and the other end, previously filled but not tamped, was now thoroughly tamped and covered with another glass plate. The following day the glass plates and the sheet metal surrounding the cylinder were removed and the cores with the mortar ends were stored in moist sand for not less than 10 days before testing.

The cores were tested in a universal type machine of 100,000 pounds' capacity. This machine was calibrated by means of an Amsler mercury-filled, steel cylinder apparatus of 120,000 pounds capacity, and the error did not exceed 0.5 per cent at any point on the scale beam. The specimens were calipered to measure the diameter from which the area was computed. The speed of the moving head was such as to apply the load at a rate of approximately 20,000 pounds per minute, the machine being operated by power. The specimens rested upon a steel cylindrical block, which rested upon the weighing table, with a semispherical steel bearing block between the upper end of the specimen and the moving head. The scale beam was kept balanced as the load was applied.

[1] The author desires to make fitting acknowledgement for the generous help rendered him by his colleagues of the engineering faculty of the University of Maryland, and particularly by S. S. Steinberg and H. B. Hoshall.

[2] Reports dealing with other phases of the investigation will follow in subsequent issues.

It was noted that the caps did not break away from the cores but acted as though integral with them. In all, 2,195 cores were tested but, for various reasons, a small percentage of the test results was discarded in making the following analyses.

RESULTS OF CORE TESTS SUMMARIZED

The average crushing strength was found to be 4,079 pounds per square inch. The individual specimens varied in strength from 1,800 pounds per square inch to 7,800 pounds. There were but four cores of the lower value and but one of the higher. The distribution of cores according to crushing strength is shown graphically in Figure 1.

The number of cores which tested less than 3,000 pounds per square inch was about 12 per cent of the total. Within a range of 1,100 pounds on either side of the mean value, that is from 3,000 pounds to 5,100 pounds per square inch, inclusive, there are included approximately 73 per cent of all the cores, leaving 15 per cent with a crushing strength greater than 5,100 pounds per square inch.

From these results it may be concluded that under the usual construction conditions that have prevailed in Maryland, concrete that will test upward of 3,000 pounds per square inch may reasonably be expected, and that concrete road cores which test much below this value are exceptional. The low values are to be accounted for only on the supposition that extraordinary conditions prevailed. Likewise, it is equally unusual to secure concrete that tests much over 5,100 pounds per square inch.

COMPARISONS MADE AS TO EFFECT OF AGE AND CHARACTER OF AGGREGATE ON STRENGTH

An analysis of the crushing strengths of the concrete cores was made to determine what influence the age of the pavement had upon the strength of the concrete.

All cores from roads 1 year old, 2 years old, and so on to 11 years (the oldest) were separated and the average strength found. The results are given in Table 1 and in diagrammatic form in Figure 2.

It is seen that the highest average was for cores 3 years old, 4,344 pounds per square inch; the lowest was for cores 9 years old, 3,790 pounds per square inch, a range of only 554 pounds, which is about equally divided above and below the average value, for all cores and for all ages, of 4,079 pounds per square inch. The obvious conclusion drawn from these data is that they indicate that no definite influence on the strength of the concrete is to be attributed to the age of the pavement within the age limits of the specimens tested.

Further analysis of the crushing strength of the cores was made on the basis of the nature of the aggregate as indicated by examination of cores with the results shown in Table 2. The highest value is for what appeared to be mixed rock (possibly crushed gravel), 4,278 pounds per square inch; the limestone aggregate being 4,241 pounds per square inch, while the lowest is for slag aggregate, 3,492 pounds per square inch. Here, too, the range is comparatively small (786 pounds), also nearly equally divided above and below the average strength of 4,079 pounds per square inch.

Since only 12 slag specimens and 27 trap-rock specimens are reported, no great significance can be attributed to the average results for these materials.

One should not attempt to draw too fine distinctions from these data for reasons which are made apparent in the following study of the general variation in the results of tests of a given number of specimens, presumably of identical concrete.

TABLE 1.—*Core strengths compared with age of concrete*

Age, years	Number of tests	Average compressive strength	Age, years	Number of tests	Average compressive strength
		Lbs. per sq. in.			*Lbs. per sq. in.*
Less than 1	67	3,806	6	139	4,062
1	745	4,093	7	162	4,083
2	417	4,226	8	145	3,995
3	77	4,344	9	41	3,790
4	122	3,835	10	50	4,025
5	80	4,054	11	48	3,804

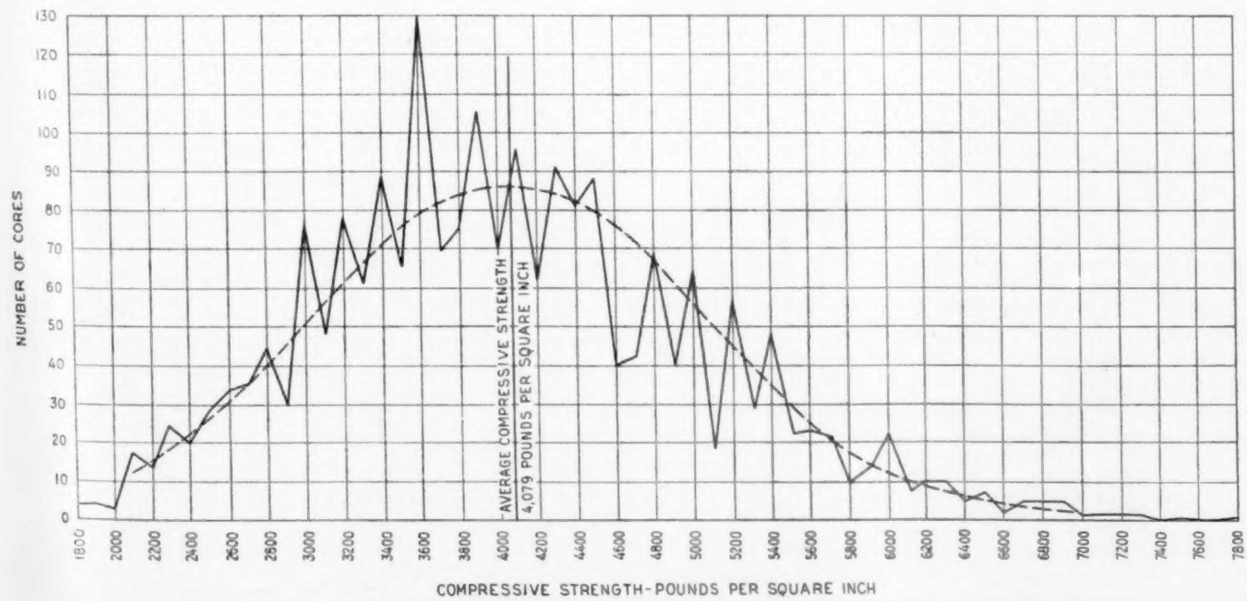


FIG. 1.—DIAGRAM SHOWING DISTRIBUTION OF CORES ACCORDING TO CORE STRENGTH

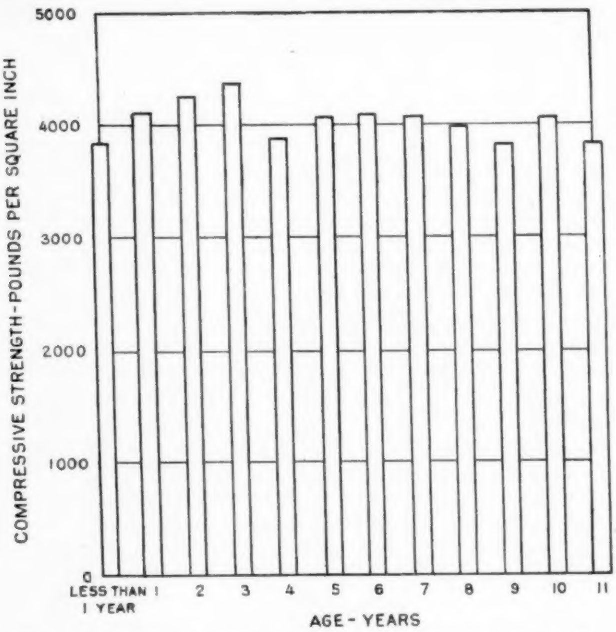


FIG. 2.—CORE STRENGTH COMPARED WITH AGE OF CONCRETE

TABLE 2.—*Core strengths compared with coarse aggregate used*

Aggregate	Number of tests	Average compressive strength	Aggregate	Number of tests	Average compressive strength
		Lbs. per sq. in.			*Lbs. per sq. in.*
Granitic	227	3,667	Sandstone	49	3,891
Gravel and rock	139	4,199	Slag	12	3,492
Mixed rock	168	4,278	Trap	27	3,838
Quartz gravel	601	3,871	Limestone	816	4,241

VARIATION IN RESULTS OF COMPRESSION TESTS DISCUSSED

As has been stated, three or more cores were drilled from about the same place in the road. Usually, one core was taken from each side and one from the center, assumed to be from concrete made and laid at the same time under the same conditions. Theoretically, the crushing strength of each specimen from such a group of cores should be the same. Practically, this is not so. For example, take three cores belonging to a group selected at random:

Core No.	Compressive strength, pounds per square inch	Variation from mean value, per cent
59	3,000	14
60	4,200	20
61	3,400	3

The mean crushing strength of these three specimens is approximately 3,500 pounds per square inch. Core No. 59 varies 14 per cent from this value; core No. 60, 20 per cent; core No. 61, 3 per cent. To illustrate further, take another group of cores:

Core No.	Compressive strength, pounds per square inch	Variation from mean value, per cent
902	5,400	6
903	4,900	4
904	5,000	2

The mean value of the compressive strength is 5,100 pounds per square inch. Core No. 902 varies 6 per cent from this mean; core No. 903, 4 per cent; core No. 904, 2 per cent. The range of variation from the mean value in the latter group is much less than the range in the first group.

Let us proceed to find the variation for each of the cores from its respective group mean (no attention being paid to the algebraic signs of the differences). The data so examined consisted of the compressive strengths of 1,557 cores, for the most part divided into groups of three, though in some cases including six, and in a few cases, nine in a group. The percentage of variation of each core from its group mean was found, as illustrated above, and the mean value of all these percentage variations of the entire 1,557 specimens was computed and found to be 8.2 per cent. It is this value which is called the "modulus of variation."

If the results are plotted, using the various individual values of percentage of variation from the mean as abscissas and the number of specimens of a given percentage as ordinates, we have for our 1,557 cores the curve shown in Figure 3. It is evident that the mean value (8.2 per cent) is the abscissa of the ordinate, which passes through the centroid of the area between the curve and the horizontal axis. It is noted that about 60 per cent of the cores had a variation less than 8.2 per cent. Under the conditions that existed it has been supposed that the cores of a given group were made of concrete of like composition and manufacture, and that the specimens were handled and treated in a like manner. That an equality of the results of compression tests of each specimen of a group is not obtained is true, (1) because the specimens may not be subjected to similar conditions during the tests; and (2) because the specimens in a group, although presumed to be of like quality, are actually of different qualities, due to variations in construction processes. Thus there result variations in the compressive strengths.

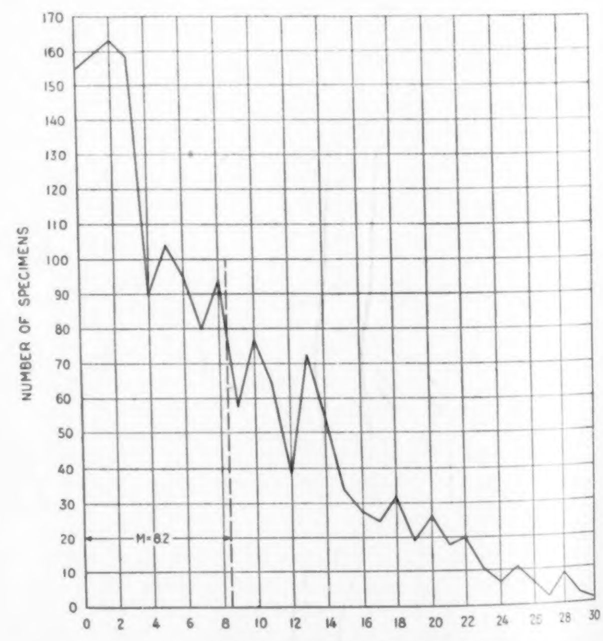


FIG. 3.—DIAGRAM SHOWING NUMBER OF CORES FROM MARYLAND ROADS VARYING FROM GROUP MEAN BY DIFFERENT PERCENTAGES. THREE CORES CONSTITUTED A GROUP. DIAGRAM BASED ON TESTS OF 1,557 CORES

The quantity 8.2 per cent is the value of the modulus of variation for the compressive strength values of this particular series of road cores, and it may well be that it is peculiar to these cores in particular, or to the particular method of testing. Thus it might happen that other methods of testing or the use of laboratory-made samples of concrete might give very much different values for the modulus of variation.

In this connection, the following data will prove of more than passing interest. A number of concrete and mortar beams, 3 by 4 inches in cross section, and about 12 inches in length were subjected to cross-breaking tests, from three to five specimens consituting a group. The mean variation, or modulus of variation, as deter-

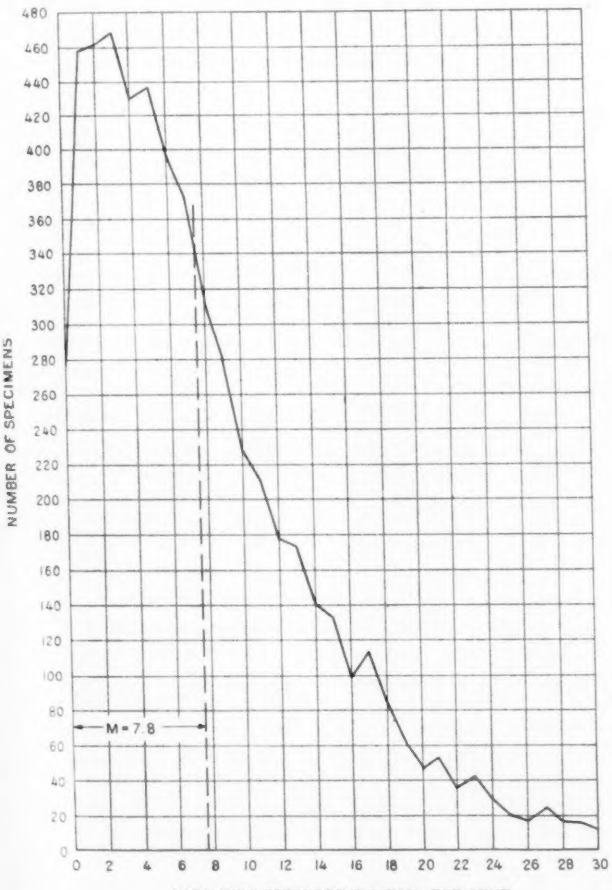


Fig. 4.—Diagram Showing Number of Concrete Cylinders Varying from Group Mean by Different Percentages. Ten Cylinders Constituted a Group. Based on Compression Tests of 5,618 Cylinders at Lewis Institute, Chicago

mined from 195 tests, was 7.1 per cent. From another group of cross-bending tests, made available through the courtesy of D. A. Abrams of the Lewis Institute, Chicago, the mean variation for 416 test specimens was found to be 10 per cent. From compression tests on laboratory-made concrete cylinders, 6 inches in diameter and 12 inches in height, made at the Lewis Institute laboratory, which included 363 test specimens, the mean variation was 7.9 per cent. From the crushing strengths of over 5,600 test specimens (these data also being furnished through the courtesy of Professor Abrams) the mean variation was found to be 7.8 per cent. The 5,600 specimens were divided into groups

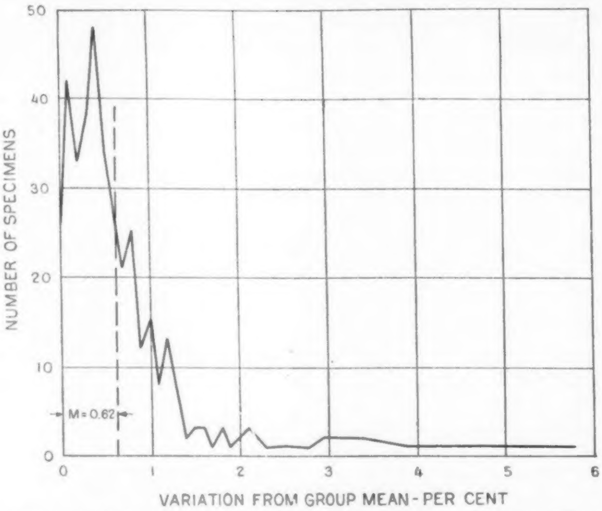


Fig. 5.—Diagram Showing Number of Steel Bars (Tested in Tension) Varying from Group Mean by Different Amounts. Three Bars Constituted a Group. Based on Tests of 393 Specimens

of 10 specimens of supposedly identical concrete, but among the groups there was included a wide variety of concrete, both as to composition, age and various other conditions of manufacture. The results are shown graphically in Figure 4. A special group of about 1,300 specimens, included within the 5,600 noted above, gave a modulus of variation of 8.1 per cent.

Thus, results of tests of concrete specimens of considerable divergence both in character and method of testing have been presented, yet there seems to be no great divergence in values found for the modulus of variation. There seems to be neither more nor less variation in the results of the crushing strength of the road cores than in the crushing strength of the laboratory-made specimens.

A still further interesting comparison was made possible through the courtesy of F. C. Langenberg, metallurgist at the Watertown Arsenal, who made available the results of tension tests of 392 samples of various kinds of steel, there being generally three specimens of each kind in a group. From these results, there was computed the modulus of variation for steel which was found to be only 0.62 per cent. A graph illustrating these results is shown in Figure 5, where it is seen that the general trend of the curve for the steel specimens is substantially the same as for the

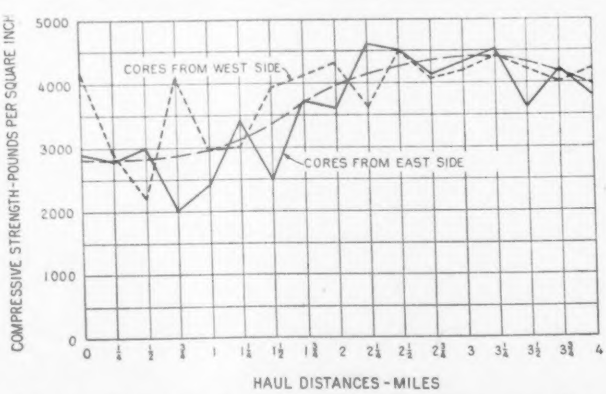


Fig. 6.—Diagram Showing Relation Between Compressive Strength and Length of Haul of Concrete Mixed at a Central Plant

concrete specimens; but the variation for the steel specimens is within much narrower limits, the average value or modulus of variation for the steel being only about 8 per cent of that for the concrete specimens, or, 0.6 per cent for the steel, as compared with 8 per cent for concrete.

This seems to indicate that the modulus of variation is indicative of the relative homogeneity of the materials, provided a sufficient number of tests of specimens is at hand to yield a characteristic value. The diagrams here shown for the crushing tests upon concrete also give information as to the reliability of an individual result when it may be compared with a group mean. Examination of Figure 3 shows that a large majority of the test results have a variation of less than 16 per cent. Basing his conclusion on this curve, the author suggests that if the variation of an individual specimen from its group mean is more than 16 or 18 per cent, this specimen may be omitted from the series as exceptional. Where but a few test results are available, such exceptional values should not be included in computations to determine a probable mean value.

EFFECT ON THE STRENGTH OF CONCRETE OF HAULING AFTER MIXING

It is often convenient to plan concrete road work so that the mixed concrete is hauled to the road from a central mixing plant. This was the method used to place the concrete shoulders on the Baltimore-Washington road near Muirkirk. The central plant was located near Muirkirk station, and the concrete was hauled varying distances up to 4 miles to construct the shoulders on each side of the road. This afforded a splendid opportunity to ascertain what effect the haul had produced on the concrete in the road. For this purpose, groups of three cores were drilled from the shoulders on each side of the road at quarter-mile intervals. Thus, there were six cores drilled one-quarter mile from the mixing plant, six at one-half mile, and so on to a total distance of 4 miles. The average compressive strength for each group of three cores is shown graphically in Figure 6. The results indicate that there is a gain in strength with increasing length of haul for the first 2 or 3 miles, and a slight falling off in strength for a haul of 4 miles. In general, the concrete that had been hauled 4 miles was somewhat stronger than that hauled but a short distance only. While the results may not warrant such precise conclusions as are indicated by the average curve drawn on the diagram, certainly it may be concluded that hauling the concrete for 3 or 4 miles, after it had been mixed, in no way injured it and probably actually increased its strength.

(Continued from p. 138)

The plan of improvement here presented has been developed throughout on the basis of facts as determined by the planning survey. The improvements planned are all necessary to a properly coordinated highway system.

The completion of the plan will relieve traffic congestion and eliminate many of the most serious traffic bottle necks in the area. Traffic conditions, however, are constantly changing, and the recurrence of present conditions can be prevented only by careful and far-sighted planning based on a definite knowledge of these changing highway and traffic conditions. Proper highway planning must be a continuous process, based on a continuing series of facts in order that the constantly increasing traffic demands may be foreseen and met with improvements as required.

(Continued from p. 147)

TABLE 6.—*Impact tests on synthetic gravel*

[Each value is the average of five tests]

Size of particle (inches)	Inches drop at failure		
	Sample 6	Sample 12	Sample 13
½ to ¾	3.0	6.0	5.0
¾ to 1	4.0	6.5	5.5
1 to 1½	6.5	6.0	7.5
1½ to 2	7.0	7.0	7.0

loss in the abrasion test. The abrasion test as now made does not differentiate between samples of uniform and nonuniform quality, and it is thought that the test should either be modified to determine the uniformity of the material or be supplanted by other tests which do determine this quality.

Certain static-load and impact tests to determine the percentage of soft or disintegrated particles in a gravel are now being investigated. These include a static-load test developed by the Iowa State Highway Commission, as well as the impact test referred to above, both of which are described in the U. S. D. A. Bulletin 1216, Revised Tentative and Standard Methods for Sampling and Testing Highway Materials, which is now in course of publication. The percentage of extremely soft or disintegrated fragments, rather than the percentage of wear on the entire sample, may prove to be the essential feature in the selection of a gravel for use in concrete.

The results of the abrasion tests made with crushed rock show that the percentage of wear averages 90 per cent of that for the standard test on hand-broken rock.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463D. Earth, Sand-clay, and Gravel Roads. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
*1077D. Portland Cement Concrete Roads. 15c.
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

DEPARTMENT BULLETINS—Continued

No. 1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 94C. T. N. T. as a Blasting Explosive.
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal Aid Highway Projects.
93M. Direct Production Costs of Broken Stone.
*105M. Federal Legislation Providing for Federal Aid in Highway Construction and the Construction of National Forest Roads and Trails. 5c.

FARMERS' BULLETIN

No. *338F. Macadam Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *739Y. Federal Aid to Highways, 1917. 5c.
*849Y. Roads. 5c.
914Y. Highways and Highway Transportation.
937Y. Miscellaneous Agricultural Statistics.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Connecticut.
Report of a Survey of Transportation on the State Highway System of Ohio.
Report of a Survey of Transportation on the State Highways of Vermont.
Report of a Survey of Transportation on the State Highways of New Hampshire.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL AID ROAD CONSTRUCTION

AS OF

AUGUST 31,1928

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total	Estimated total cost	Federal aid allotted	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total		
Alabama	1,802.0	$ 4,756,110.06	$ 2,362,491.43	292.6	31.2	323.8	$ 860,652.76	$ 430,013.32	45.2	12.4	57.6	$ 1,344,915.31	Alabama
Arizona	866.3	1,587,108.49	1,289,600.56	66.8	4.8	71.6	154,944.82	112,087.06	7.5	.1	7.6	2,783,937.59	Arizona
Arkansas	1,678.2	4,889,177.23	2,191,181.20	180.7		180.7	260,157.29	116,258.35	9.9	6.6	16.5	1,746,672.15	Arkansas
California	1,454.9	7,770,745.30	3,628,722.16	176.9	9.3	186.2	1,736,787.47	724,528.38	48.3		48.3	2,579,925.07	California
Colorado	987.8	5,206,321.96	2,688,210.60	194.6	9.2	203.8	862,396.92	458,159.27	33.6	14.5	48.1	2,068,504.12	Colorado
Connecticut	207.6	2,797,123.09	597,011.44	33.3		33.3	285,289.67	66,951.17	3.6		3.6	566,752.61	Connecticut
Delaware	195.6	470,022.22	95,739.75	5.7	4.0	9.7	421,823.60	196,095.90	15.6		15.6	149,880.44	Delaware
Florida	401.6	3,707,532.37	1,547,155.88	83.9	5.4	89.3	905,396.31	333,505.44	30.7		30.7	1,212,651.02	Florida
Georgia	2,435.8	4,621,671.86	2,228,596.14	193.5	52.4	245.9	2,028,308.49	768,037.90	87.4	18.4	105.8	4,406.00	Georgia
Idaho	963.8	1,885,258.19	1,119,916.29	92.2	54.6	146.8	1,160,394.88	691,938.36	112.0	1.8	113.8	85,032.18	Idaho
Illinois	1,701.1	21,707,064.28	10,000,199.10	674.5		674.5	2,142,620.75	1,021,021.40	80.2		80.2	27,550.17	Illinois
Indiana	1,110.8	9,501,911.13	4,534,935.00	289.4	3.5	292.9	1,153,418.55	564,119.27	44.1		44.1	127,949.39	Indiana
Iowa	2,865.3	6,281,671.93	2,658,186.52	126.0	127.9	253.9	1,356,950.68	565,111.52	5.1	60.3	65.4	171,313.77	Iowa
Kansas	2,239.3	4,747,264.01	1,910,768.72	258.5		258.5	3,338,010.45	1,293,117.96	213.7	16.3	230.0	393,230.20	Kansas
Kentucky	1,179.9	5,221,065.95	2,583,925.05	231.8		231.8	1,461,138.84	705,734.17	87.1		87.1	8,677.83	Kentucky
Louisiana	1,276.1	4,169,692.49	2,077,087.60	198.3		198.3	312,902.34	129,923.52	3.2		3.2	437,598.06	Louisiana
Maine	428.7	1,398,515.49	564,307.60	42.1		42.1	1,677,842.31	530,449.23	39.3		39.3	1,015,874.63	Maine
Maryland	564.8	557,576.12	269,630.00	22.6		22.6	1,195,181.30	521,145.00	47.6	7.2	54.8	39,571.23	Maryland
Massachusetts	510.7	4,015,451.84	1,203,207.82	76.0		76.0	1,090,560.04	369,172.14	20.8		20.8	1,662,884.46	Massachusetts
Michigan	1,343.2	13,940,657.09	5,931,948.08	359.4		359.4	962,043.88	410,245.00	22.2	6.5	28.7	338,729.95	Michigan
Minnesota	3,842.5	6,429,628.03	2,123,100.00	322.5	56.7	379.2	1,670,980.12	129,000.00	34.8	20.6	55.4	393,471.43	Minnesota
Mississippi	1,532.9	4,863,120.98	2,272,464.47	236.3	31.6	267.9	1,041,854.81	315,048.71	22.2		22.2	562,842.23	Mississippi
Missouri	2,214.2	5,463,614.84	2,268,734.94	166.0	44.8	210.8	1,581,131.84	694,239.61	55.6	12.9	68.5	1,018,306.04	Missouri
Montana	1,329.3	3,989,703.89	2,419,948.63	350.0	7.4	357.4	1,295,152.14	708,566.41	127.5	13.3	140.8	4,339,426.40	Montana
Nebraska	3,195.4	5,515,251.96	2,751,045.54	554.8	153.4	708.2	323,117.06	161,012.94	20.5	28.2	48.7	1,894,612.04	Nebraska
Nevada	1,051.1	860,936.20	756,108.50	96.8	36.4	133.2	161,846.40	132,697.83	0.4	25.8	26.2	450,391.64	Nevada
New Hampshire	305.6	863,537.39	350,965.16	24.2		24.2	470,059.49	177,875.78	8.4		8.4	615.07	New Hampshire
New Jersey	427.8	5,215,381.41	939,177.35	64.6		64.6	868,654.88	124,005.00	8.3		8.3	86,765.94	New Jersey
New Mexico	1,766.1	2,868,058.42	1,882,709.07	183.7	0.5	184.2	607,856.46	384,764.83	34.4		34.4	464,073.83	New Mexico
New York	1,878.6	31,383,000.00	7,243,387.50	464.6	8.6	473.2	8,347,700.00	1,751,955.00	116.9		116.9	3,554,470.63	New York
North Carolina	1,592.7	2,324,095.07	1,128,758.05	78.4	20.3	98.7	646,583.70	318,529.10	18.9	12.2	31.1	765,695.89	North Carolina
North Dakota	3,291.4	3,547,573.53	1,632,706.52	625.8	150.1	775.9	886,525.36	356,192.01	134.1	97.9	232.0	423,326.32	North Dakota
Ohio	1,827.4	12,559,136.74	4,531,288.32	274.4	6.0	280.4	4,785,122.10	1,616,681.04	99.9	12.7	112.6	1,692,111.86	Ohio
Oklahoma	1,601.1	3,324,467.82	1,589,725.83	165.8	6.3	172.1	1,864,177.12	816,126.50	104.1	20.4	124.5	332,154.21	Oklahoma
Oregon	1,106.0	1,619,124.26	911,201.62	45.3		45.3	216,192.90	111,735.02	14.1		14.1	1,226,909.14	Oregon
Pennsylvania	1,861.6	13,719,248.21	3,930,817.73	241.4		241.4	5,554,982.33	1,662,793.85	104.9		104.9	1,092,795.47	Pennsylvania
Rhode Island	150.8	900,832.77	248,913.92	14.7		14.7	112,609.50	43,974.55	1.6		1.6	576,046.16	Rhode Island
South Carolina	1,652.3	8,217,585.23	1,776,674.99	195.1	120.7	315.8	228,913.59	45,000.00		8.2	8.2	66,880.90	South Carolina
South Dakota	2,986.1	3,144,076.11	1,685,307.87	511.1	81.7	592.8	362,315.24	193,773.29	101.2	21.8	123.0	311,479.70	South Dakota
Tennessee	1,087.5	4,434,854.96	1,937,375.20	127.1		127.1	3,938,496.78	1,262,990.08	25.6	94.3	119.9	255,543.76	Tennessee
Texas	5,958.6	9,753,644.36	3,927,066.62	226.0	156.3	382.3	6,214,103.59	2,632,199.30	227.2	134.5	361.7	3,400,336.71	Texas
Utah	845.7	1,599,464.70	1,086,104.33	83.7	5.4	89.1	482,306.98	349,876.34	39.2	54.2	93.4	39,574.75	Utah
Vermont	201.3	2,512,809.19	663,942.33	54.5		54.5	284,662.92	55,000.00	6.3		6.3	38,964.23	Vermont
Virginia	1,267.0	4,345,329.44	1,323,173.44	99.2	21.6	120.8	1,352,111.47	363,304.98	55.7		55.7	11,604.44	Virginia
Washington	777.7	4,106,232.53	1,403,000.00	105.4	18.1	123.5	1,173,948.35	476,156.27	24.5	5.0	29.5	479,924.08	Washington
West Virginia	607.0	2,781,092.00	1,240,175.25	105.6		105.6	1,189,819.13	529,006.09	39.6	12.4	52.0	248,198.88	West Virginia
Wisconsin	2,082.2	8,054,515.78	3,098,223.70	271.9	27.5	299.4	620,819.70	145,765.59	14.9	9.9	24.8	1,437,126.56	Wisconsin
Wyoming	1,472.0	2,418,783.01	1,517,730.23	256.8	26.2	283.0	137,907.22	88,536.41	15.9		15.9	35,095.74	Wyoming
Hawaii	36.2	301,973.76	60,383.43	3.2		3.2	175,931.99	57,501.20	1.8		1.8	1,064,241.58	Hawaii
TOTALS	72,159.6	286,346,013.67	106,177,047.37	9,547.7	1,281.9	10,829.6	69,951,674.51	25,711,921.99	2,415.6	728.4	3,144.0	43,014,819.81	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.